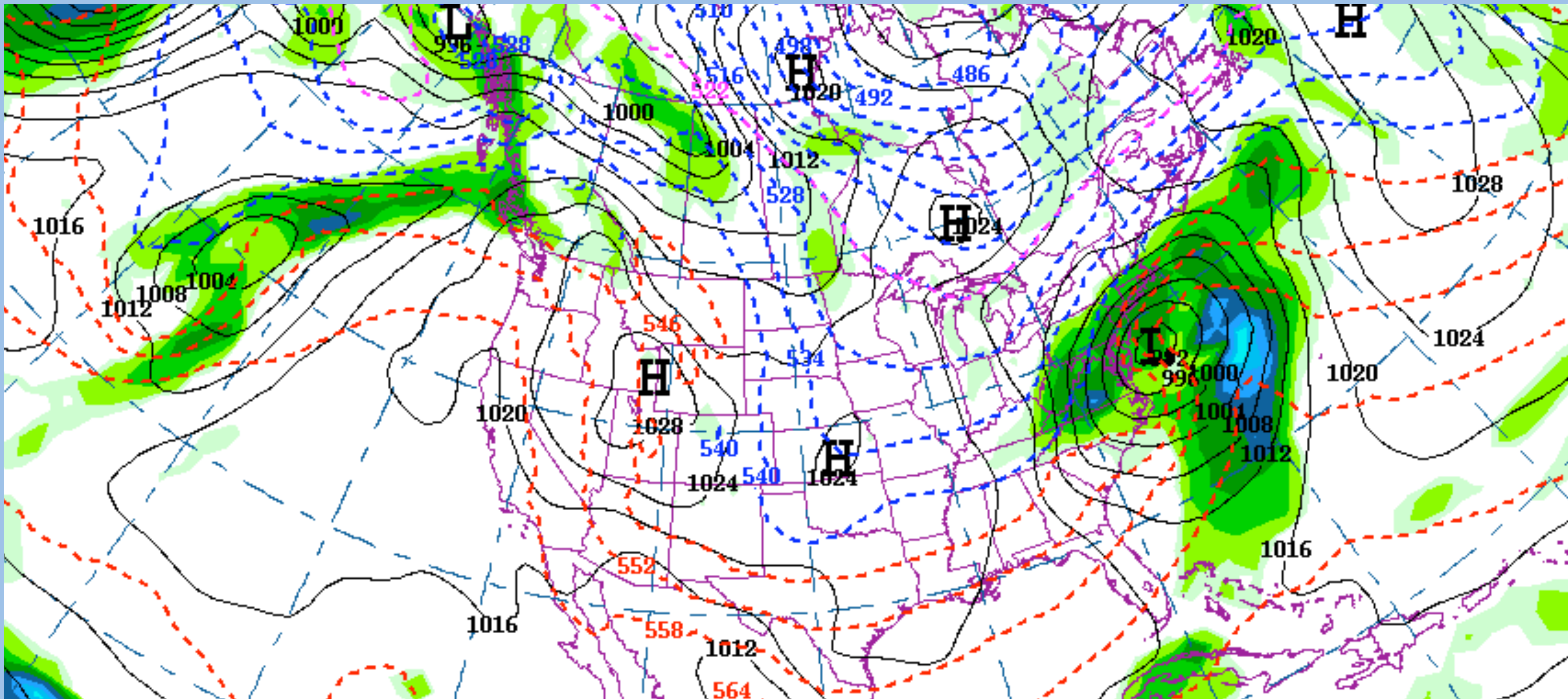

(some comments on)
The Influence of the Gulf Stream on the North Atlantic Storm Tracks

Jimmy Booth
LuAnne Thompson, Suzanne Dickinson
Jerome Patoux, Kathryn A Kelly
University of Washington
NASA Ocean Vector Winds Science Team Program

figure source: David Ovens,UW

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Is the Gulf Stream responsible for Europe's mild winters?

By R. SEAGER[1]*, D. S. BATTISTI[2], J. YIN[2], N. GORDON[1], N. NAIK[1], A. C. CLEMENT[3] and M. A. CANE[1]

SUMMARY

Is the transport of heat northward by the Gulf Stream and North Atlantic Drift, and its subsequent release into the midlatitude westerlies, the reason why Europe's winters are so much milder than those of eastern North America and other places at the same latitude? Here, it is shown that the principal cause of this temperature difference is advection by the mean winds. South-westerlies bring warm maritime air into Europe and north-westerlies bring frigid continental air into north-eastern North America. Further, analysis of the ocean surface heat budget shows that the majority of the heat released during winter from the ocean to the atmosphere is accounted for by the seasonal release of heat previously absorbed and not by ocean heat-flux convergence. Therefore, the existence of the winter temperature contrast between western Europe and eastern North America does not require a dynamical ocean. Two experiments with an atmospheric general-circulation model coupled to an ocean mixed layer confirm this conclusion. The difference in winter temperatures across the North Atlantic, and the difference between western Europe and western North America, is essentially the same in these models whether or not the movement of heat by the ocean is accounted for. In an additional experiment with no mountains, the flow across the ocean is more zonal, western Europe is cooled, the trough east of the Rockies is weakened and the cold of north-eastern North America is ameliorated. In all experiments the west coast of Europe is warmer than the west coast of North America at the same latitude whether or not ocean heat transport is accounted for. In summary the deviations from zonal symmetry of winter temperatures in the northern hemisphere are fundamentally caused by the atmospheric circulation interacting with the oceanic mixed layer.

Take home messages of the talk

•The presence of the Gulf Stream is important to the climatological mean position of the North Atlantic storm track.

•The Gulf Stream forcing of variability in midlatitude storms is not detectable in the ERA-40 Reanalysis.

Take home messages of the talk

? •The presence of the Gulf Stream is important to the climatological mean position of the North Atlantic storm track.

✓ •The Gulf Stream forcing of variability in midlatitude storms is not detectable in the ERA-40 Reanalysis.

Midlatitude Storms and Storm Tracks

Midlatitude Storms: transient low-pressure (cyclonic) systems; associated with surface temperature fronts; the weather makers in NYC.

Storm Tracks: regions of strong baroclinic wave activity [Blackmon et al. 1977]

-Apply time filter to isolate variability associated with baroclinic waves

-calculate the variance or covariance of the filtered data

E.g. 2-6 day bandpass-filter (remove variability <2day and >6 day)

{Simple 24-hour differencing acts in a similar manner}

$\overline{\tilde{v}\tilde{T}}$: transient eddy heat transport.

~ :: bandpass filtered field

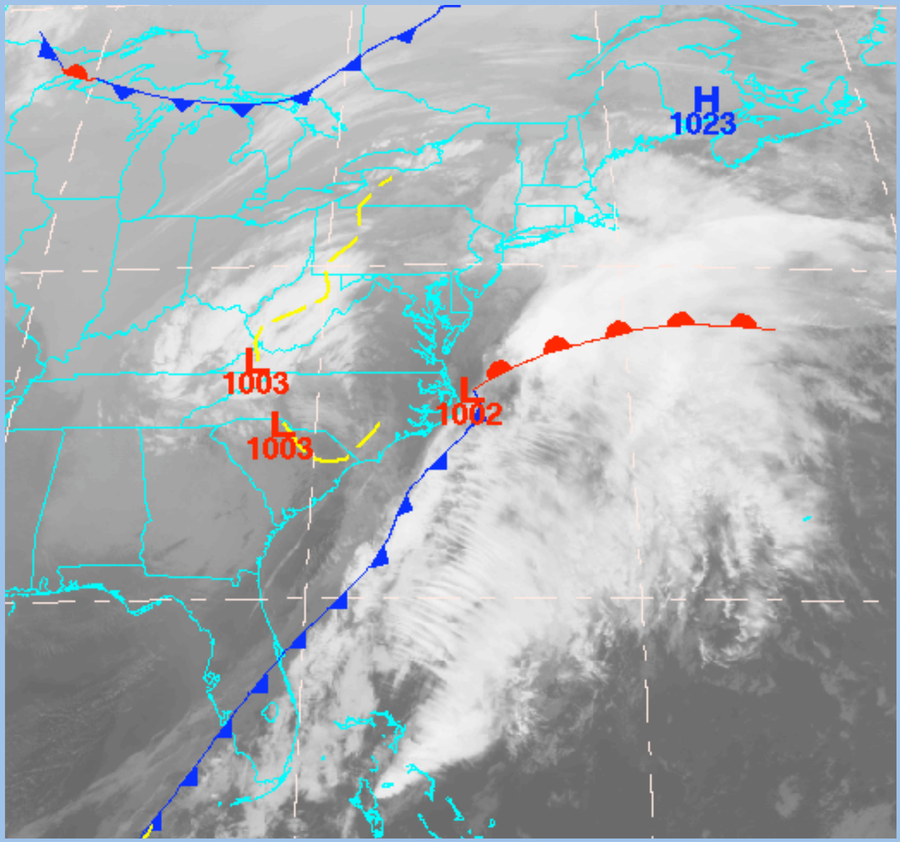

figure source: David Ovens,UW

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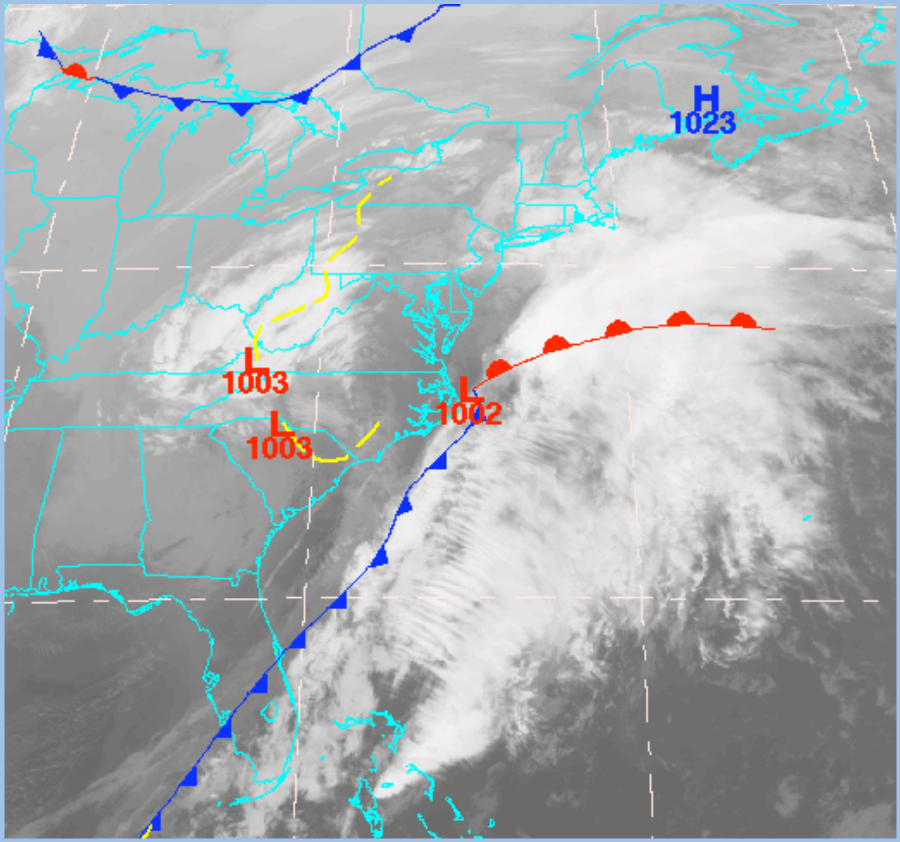


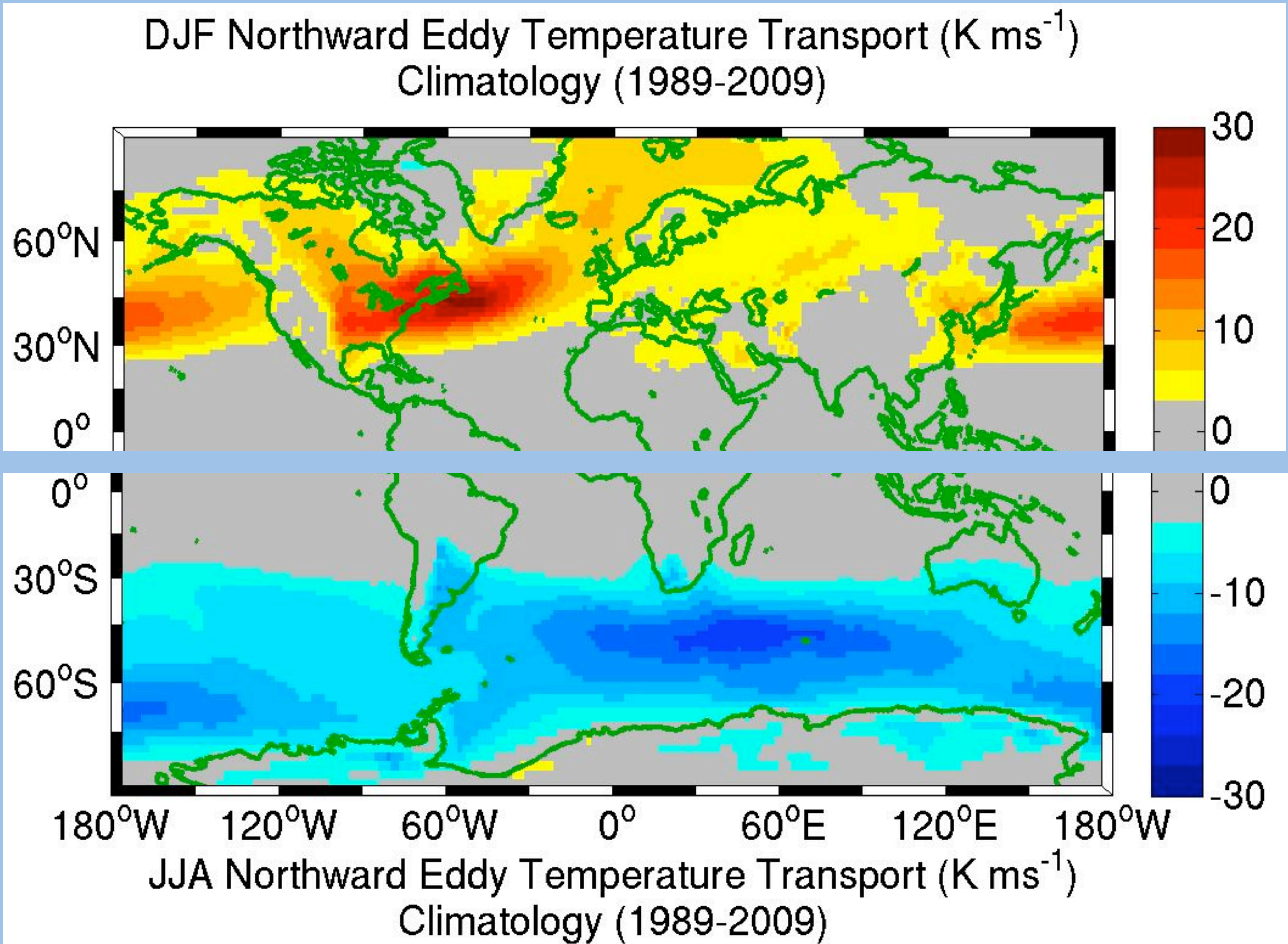
Can we think of storm tracks as climatological analogs for midlatitude storms?

-Composite position of maximum winds within individual storms does have a similar distribution to the storm tracks. [Hoskins and Hodges 2002, 2005]

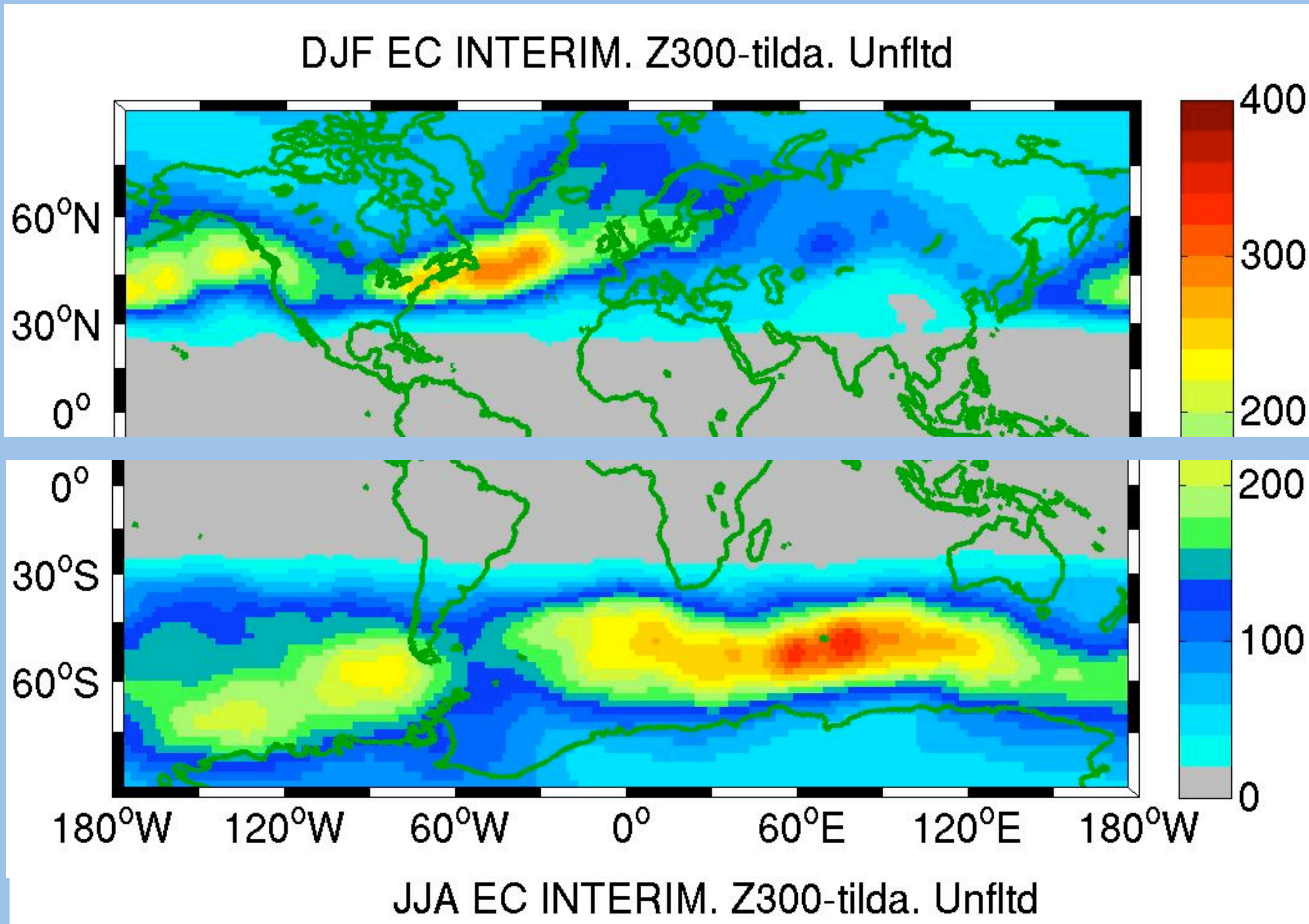
Why do storms/storm tracks matter?

-storm tracks transport heat and moisture poleward and maintain the surface westerlies

The Climatological Storm Tracks $\overline{\tilde{v}\tilde{T}}$



The Climatological Storm Tracks $\overline{\tilde{Z}_{300}^2}$



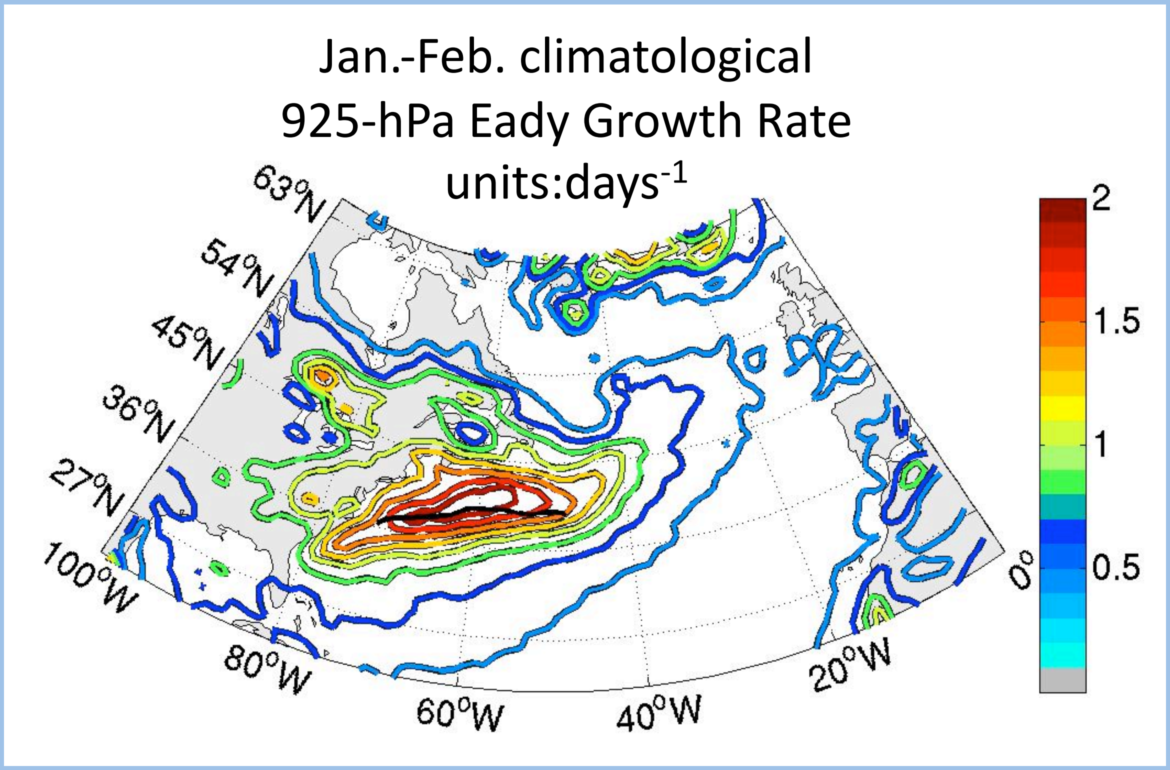
Storm Dynamics

Midlatitude storms typically form due to instabilities associated with vertical sheer in the zonal wind.

A metric often used to identify regions of storm track formation:

Eady growth rate

$$\sigma_{BI} = \frac{0.31f}{N}\frac{du}{dz} = -\frac{0.31g}{N\theta}\frac{\partial\theta}{\partial y}$$



Upper level wave activity is correlated with 925-hPa [Nakamura and Shimpo 2004]

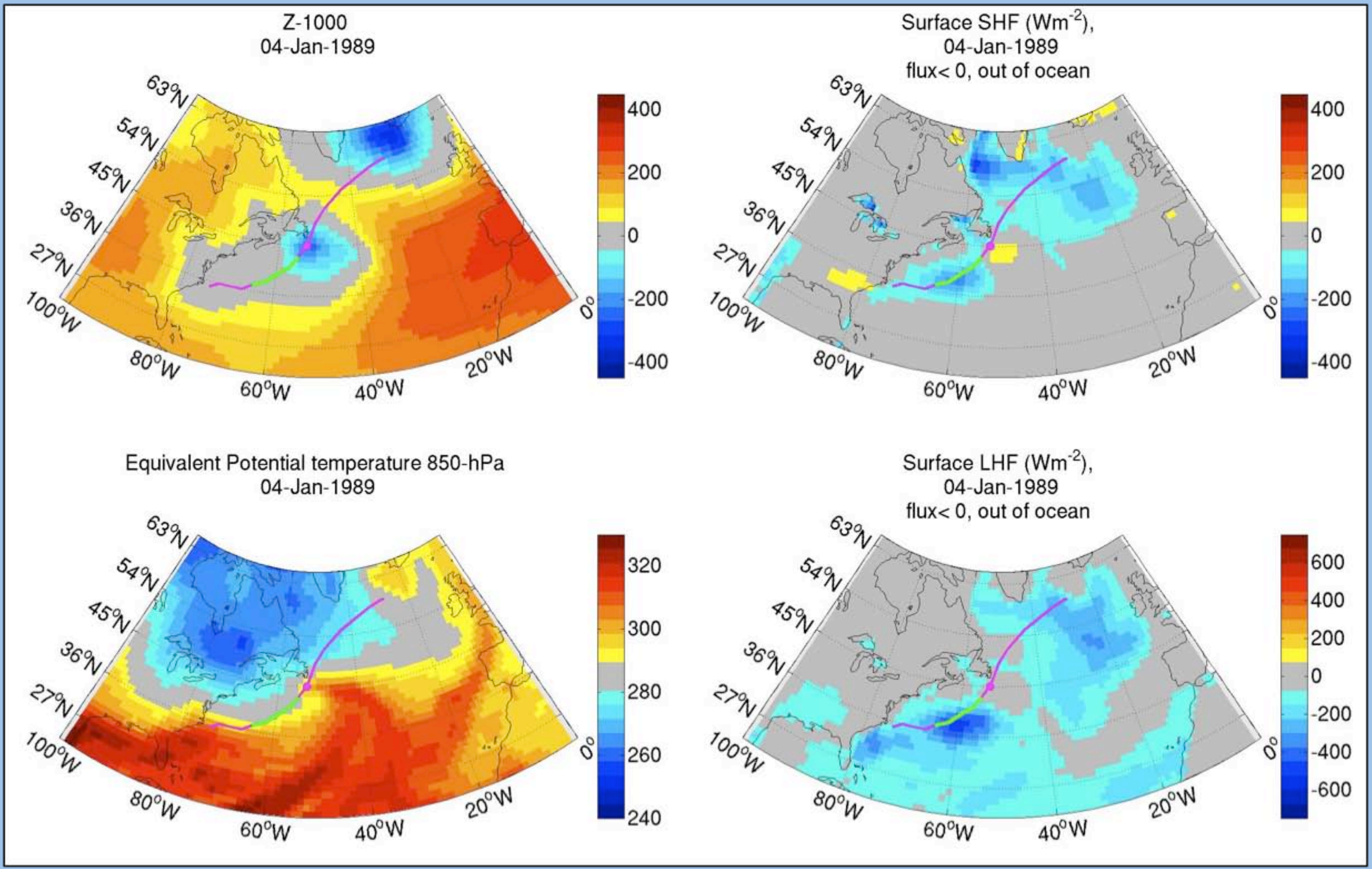
Midlatitude storm amplification (deepening of the low center) occurs primarily due the differential temperature advection with respect to pressure. [e.g. Carlson 1991 or Holton 2004]

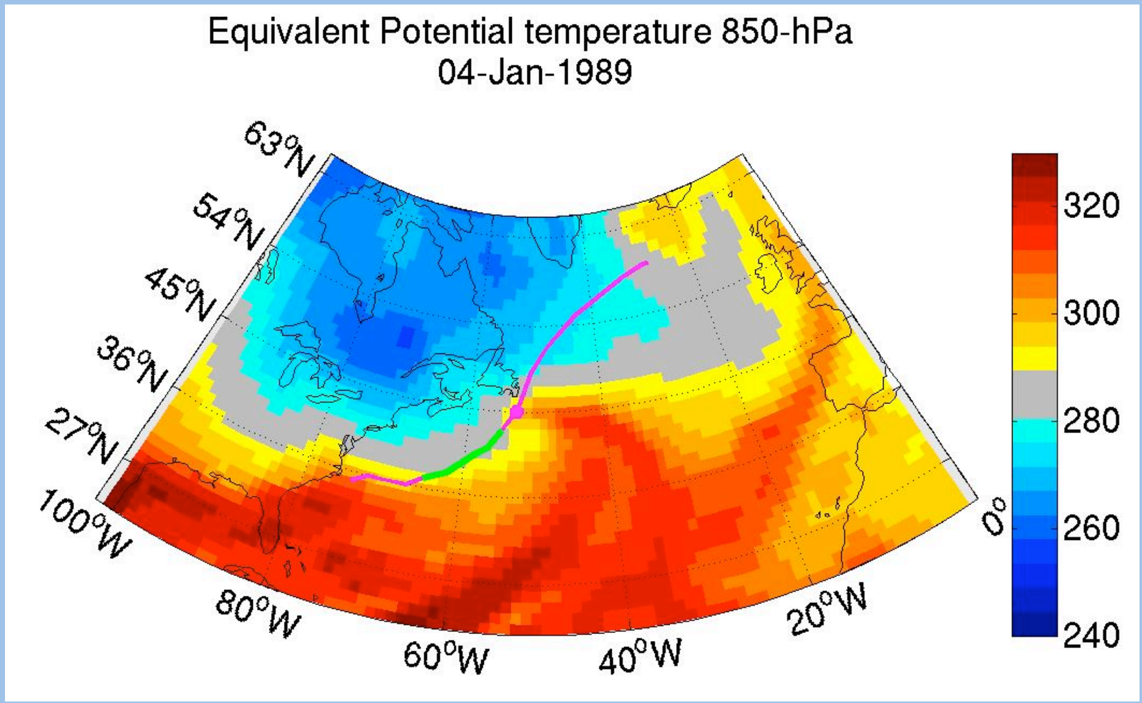
Typical storm genesis: upper-level wave disturbance + low-level temperature gradient

Storm Interactions with the Ocean

-fluxes of moisture and heat from the surface provide an energy source to the storms, as the rise air saturates and releases latent heat. . [Reed et al. 1993

-the storm can loose energy to the ocean through sensible heat fluxes. [Kuo et al. 1992]





Storms' circulations act to remove the surface temperature gradient,
so why are do they have fixed locations?

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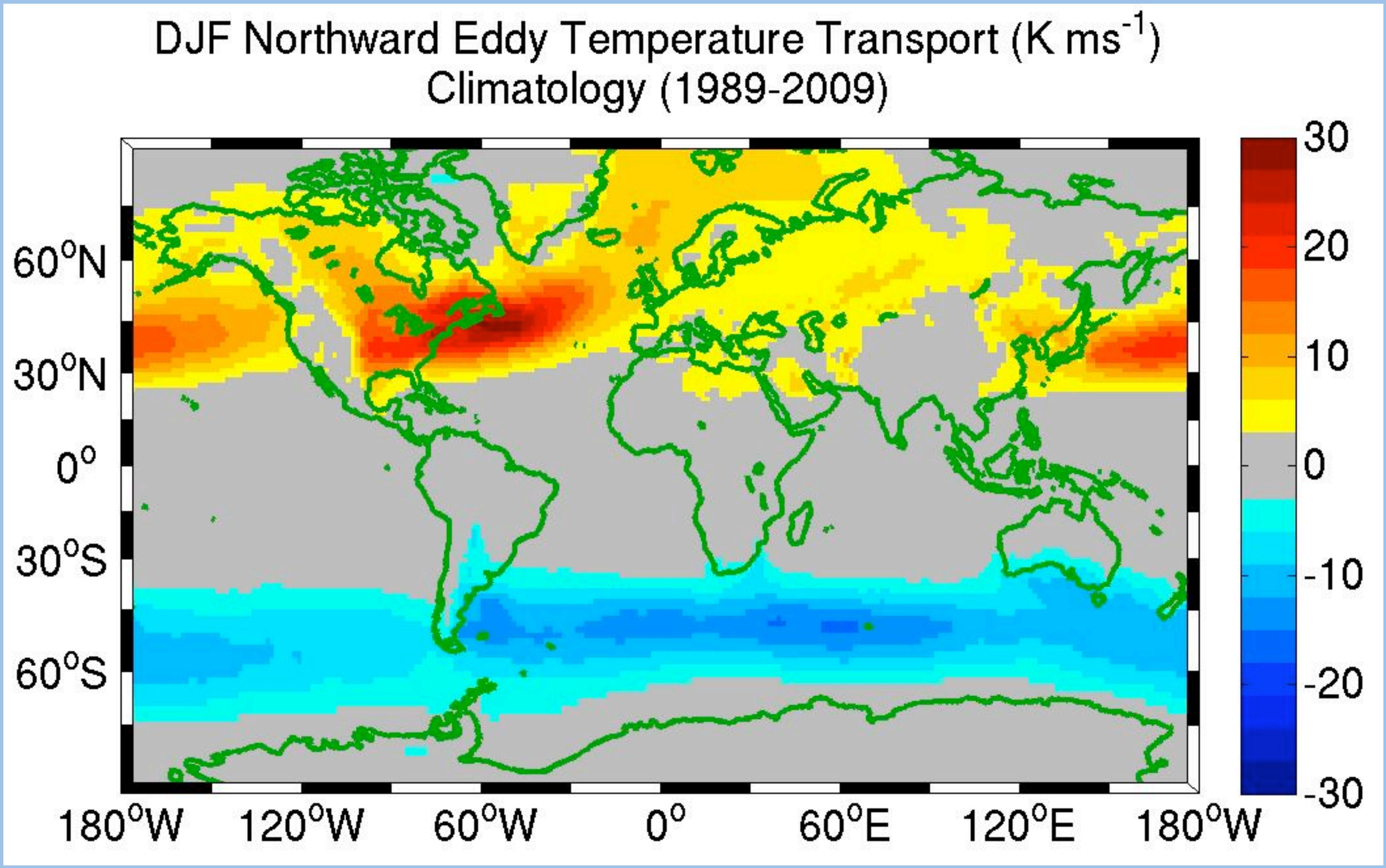
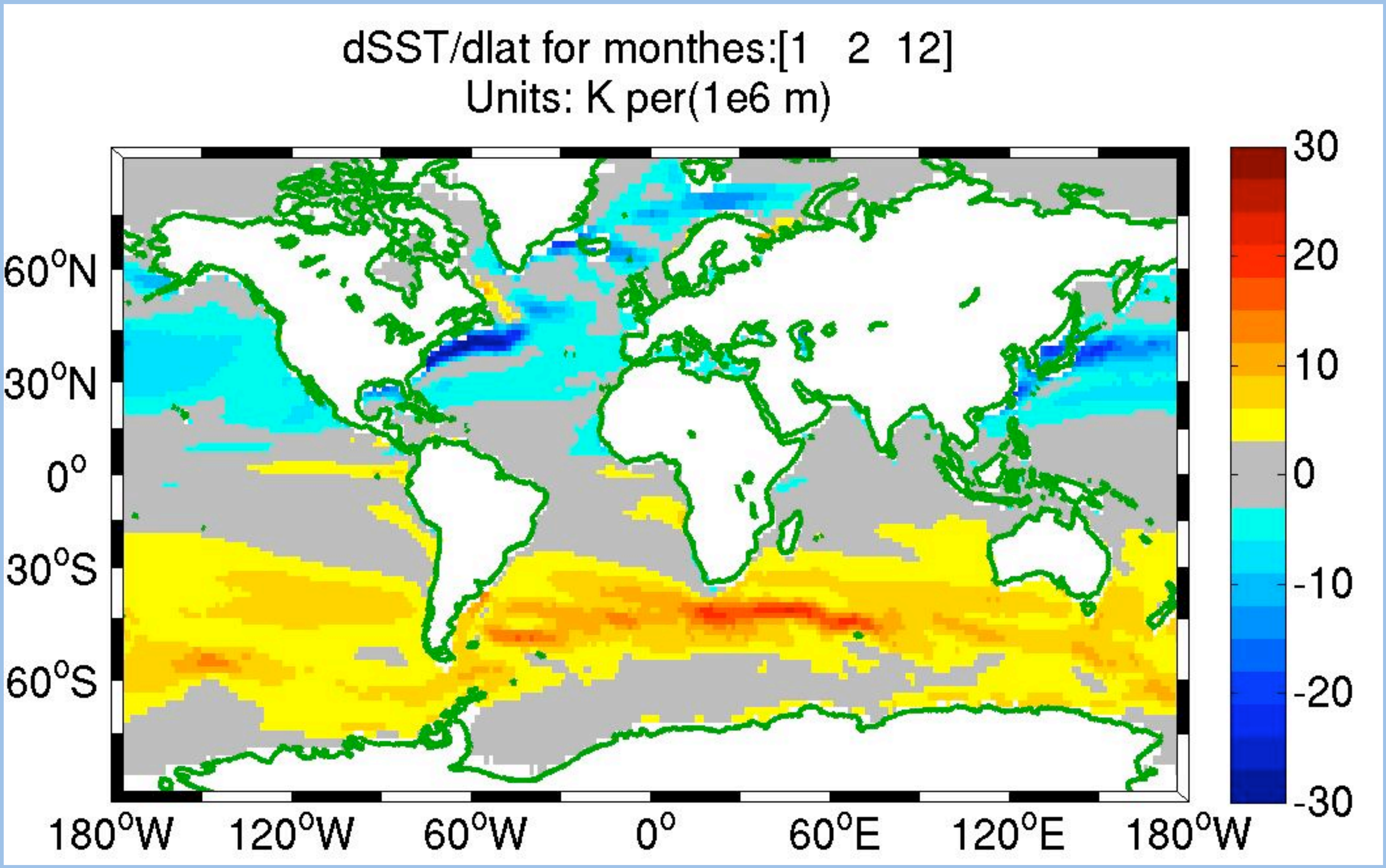


What sets the position of the storm tracks?

Theory: Ocean circulation associated with strong western boundary currents creates fixed surface baroclinic zones that anchor the storm track location.

[Nakamura et al. 2008]



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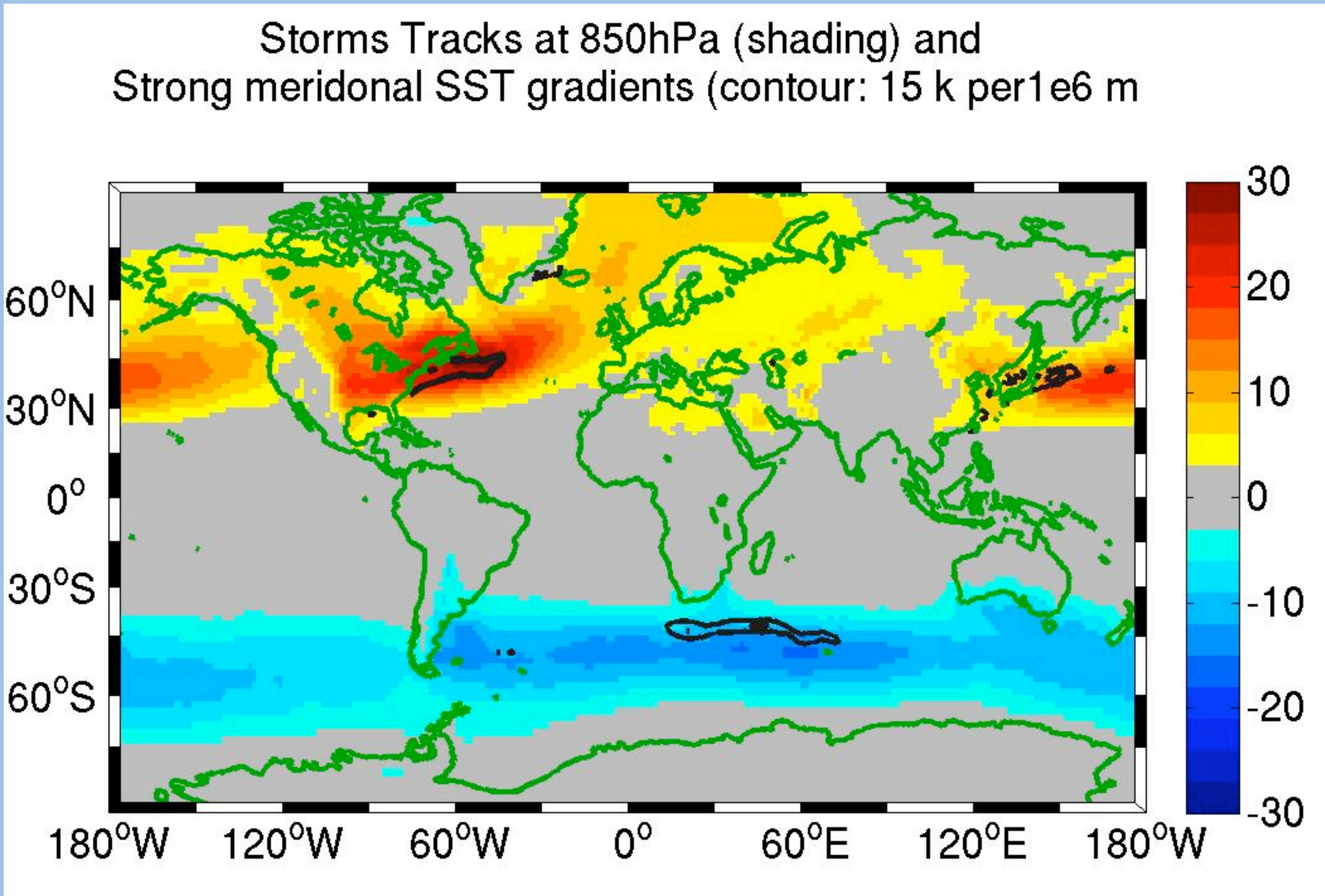
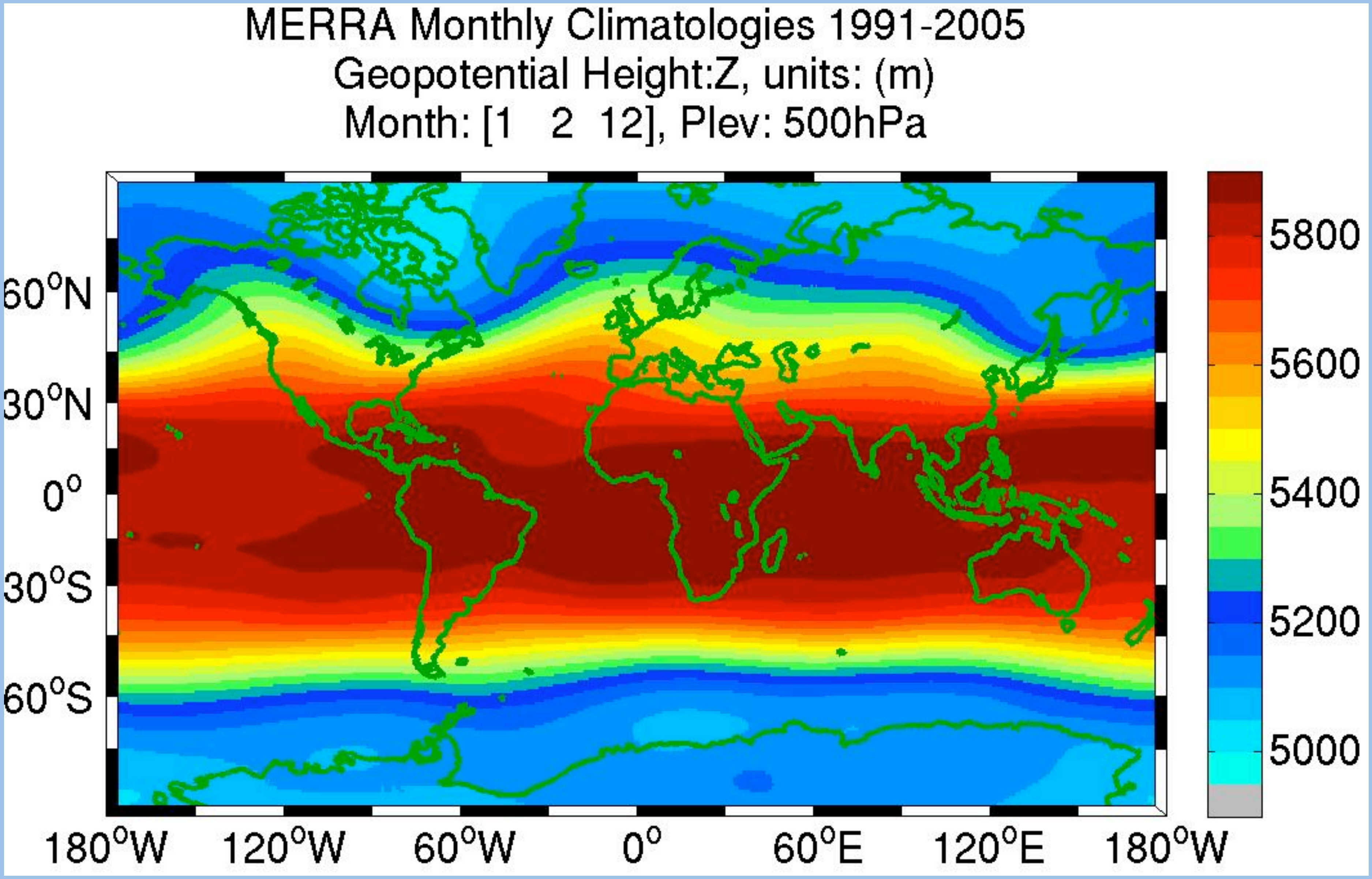


What sets the position of the storm tracks?

Theory: Mountains set-up the stationary waves which create location of upper level trough; trough anchors location of upper-level disturbances.

[Manabe and Broccoli 1990]



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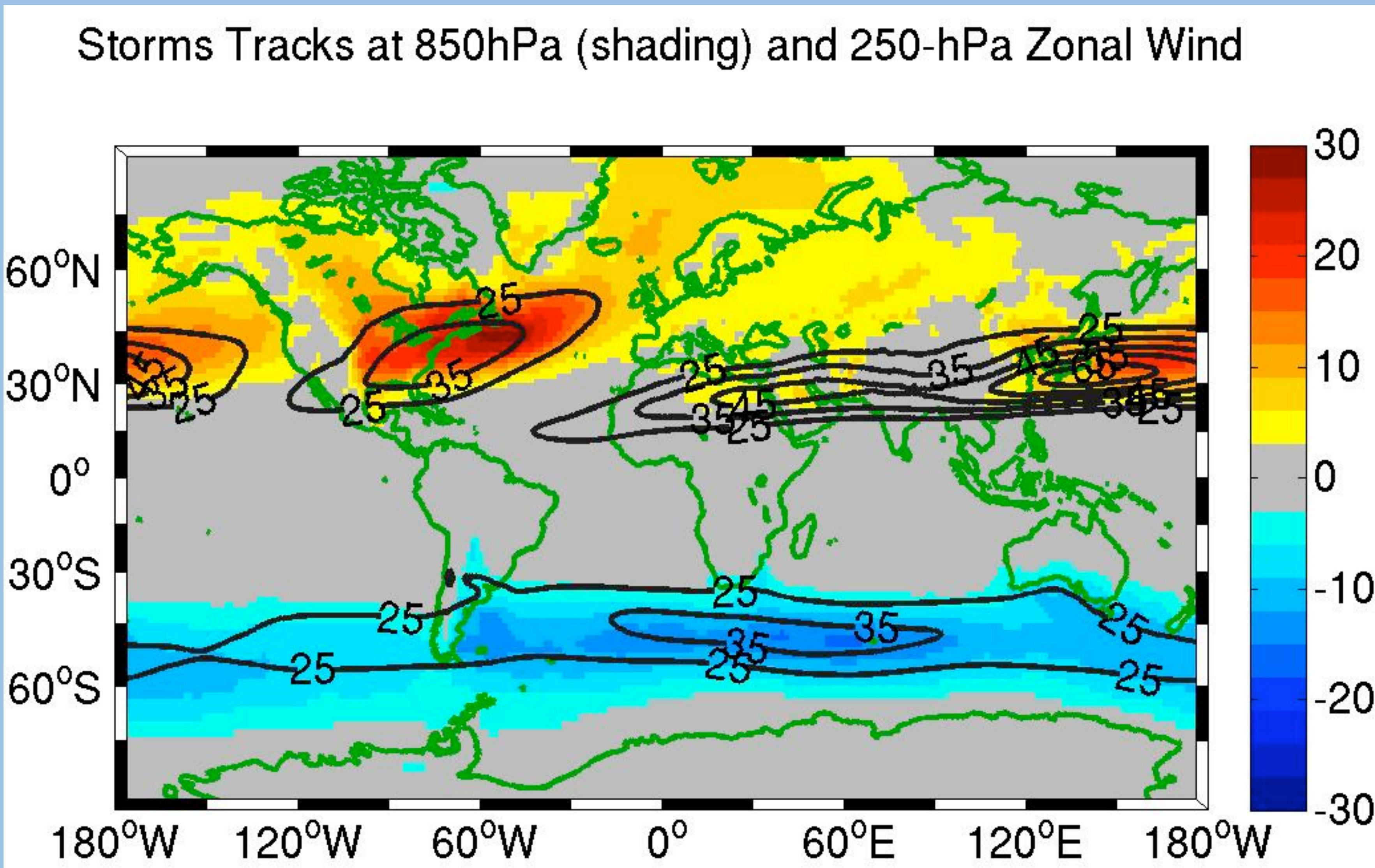


However: stationary wave distribution depends on diabatic heating from ocean.

[Held et al. 2002]

SEPTEMBER 2009
JOURNAL OF THE ATMOSPHERIC SCIENCES

The Basic Ingredients of the North Atlantic Storm Track. Part I: Land–Sea Contrast and Orography

DAVID JAMES BRAYSHAW
Walker Institute, Department of Meteorology, University of Reading, Reading, Berkshire, United Kingdom

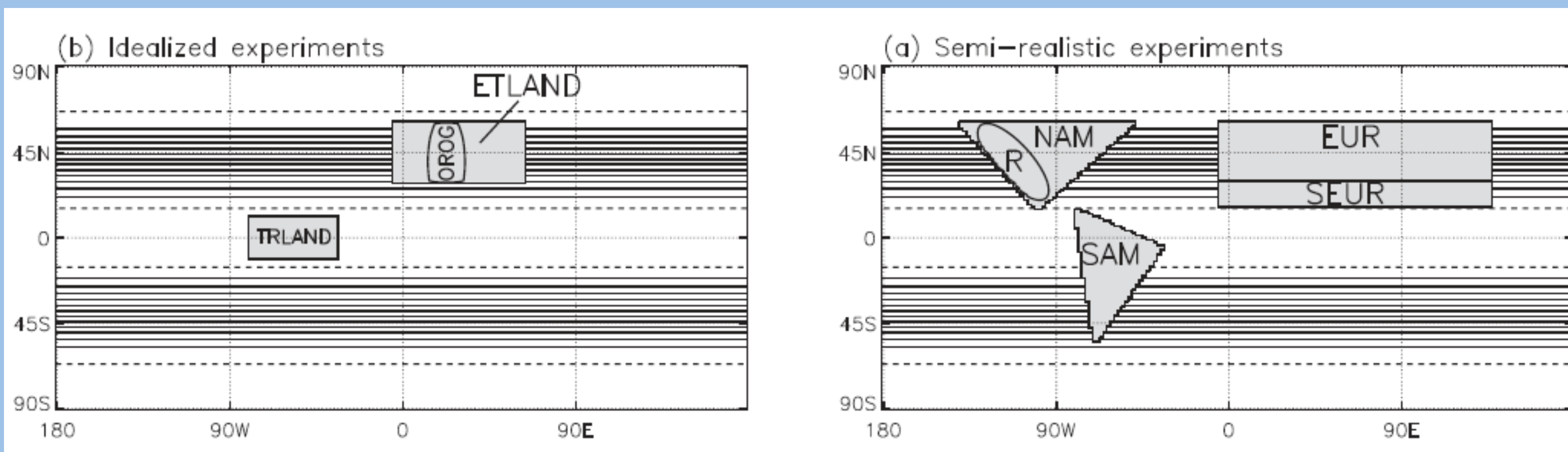
BRIAN HOSKINS
Department of Meteorology, University of Reading, Reading, Berkshire, United Kingdom

MICHAEL BLACKBURN

Experiment Design

Run full AGCM *{HAD AM3}* simulations with idealized SST boundary conditions:
-add idealized continents
-add idealized orography.

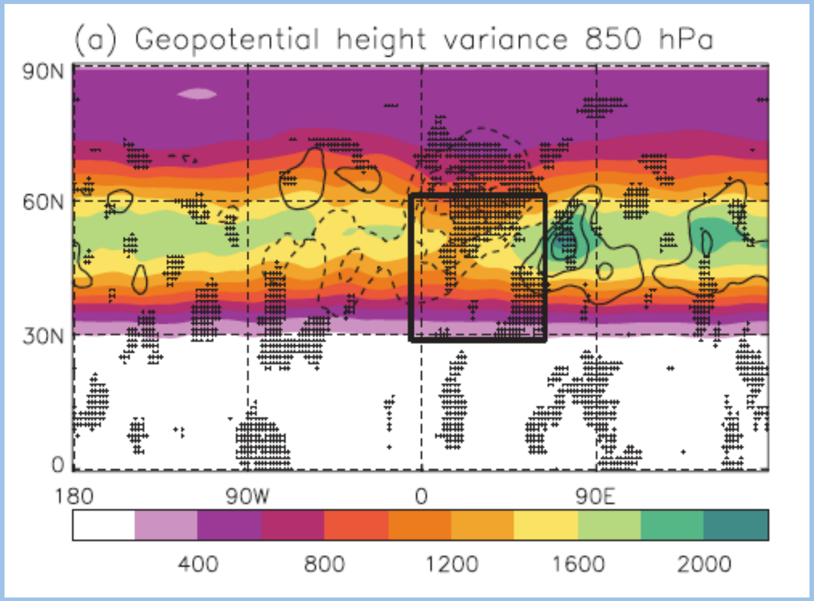
Perpetual Equinox Conditions



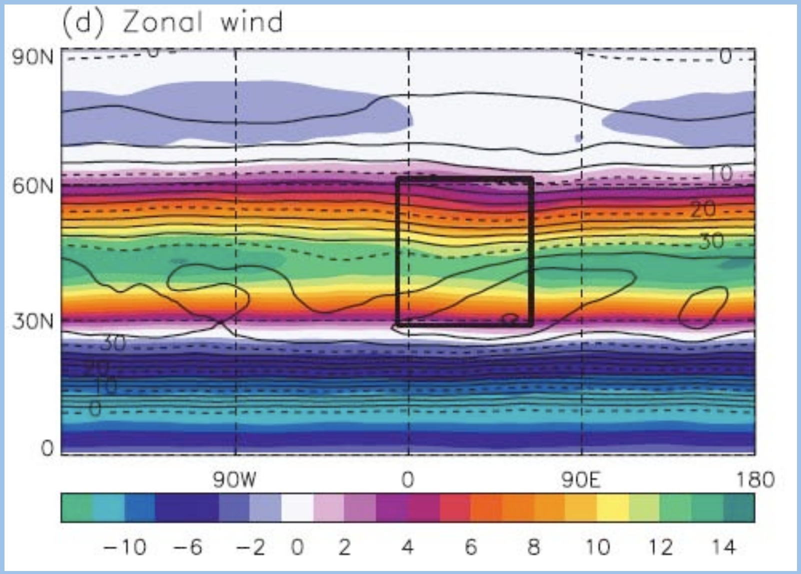
*Fixed SST Boundary Condition
(This study will not explain the importance of ocean circulation, but it will layout the relative roles of mountains and land/sea configuration.

Simple landmass in extratropics vs. base state (no land & no orography)

Storm Track



Zonal Wind



Black Box: land boundary
Shading: storm tracks at 850hPa
Contours:
solid: stronger S/T than base case
dashed: weaker S/T than base case

Black Box: land boundary
Shading: zonal wind at 850hPa
Contours:
Solid and dashed:
Zonal wind at 250hP

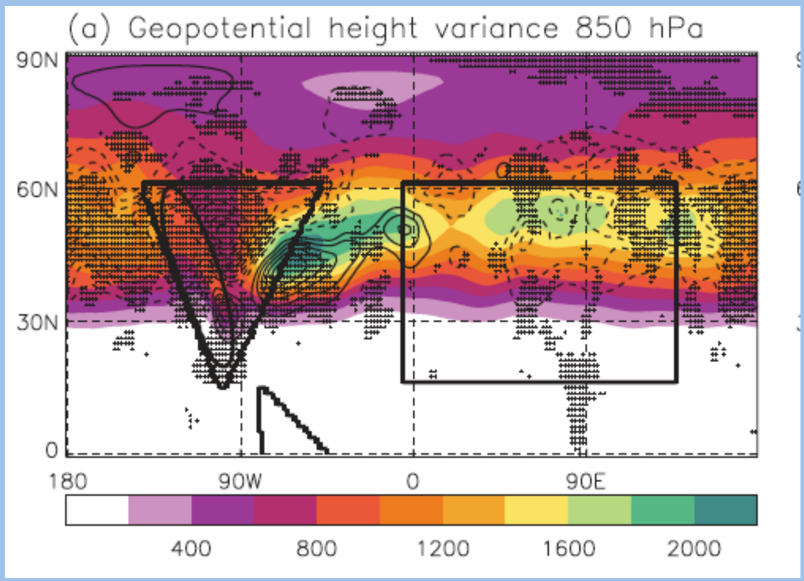
Results: simple landmass breaks up the zonal symmetry of the storm track.

However: the storm track does not have a SW to NE tilt, is not organized into a continuous lateral region.

Brayshaw et al. 2009

Semi-realistic landmasses in extratropics vs. base state (no land & no orography)

Storm Track



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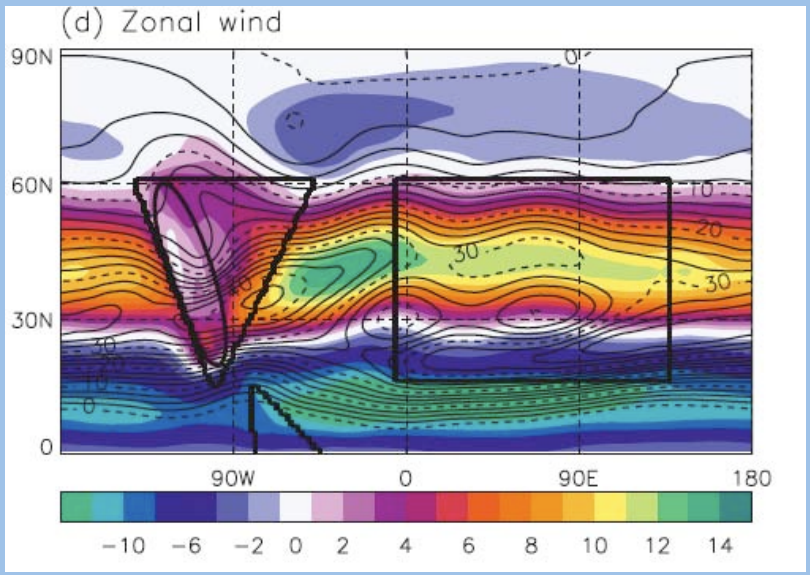

Black Box: land boundary
Shading: zonal wind at 850hPa
Contours:
Solid and dashed:
Zonal wind at 250hP

Results: The storm track maxima is located on the poleward edge of the zonal wind maxima.
Both the S/T and the zonal wind maxima have a SW to NE tilt.

Brayshaw et al. 2009

The Basic Ingredients of the North Atlantic Storm Track. Part I: Land–Sea Contrast and Orography

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Walker Institute, Department of Meteorology, and National Centre for Atmospheric Science, University of Reading, Reading, Berkshire, United Kingdom

(Manuscript received 22 January 2009, in final form 17 April 2009)

ABSTRACT

Understanding and predicting changes in storm tracks over longer time scales is a challenging problem, particularly in the North Atlantic. This is due in part to the complex range of forcings (land–sea contrast, orography, sea surface temperatures, etc.) that combine to produce the structure of the storm track. The impact of land–sea contrast and midlatitude orography on the North Atlantic storm track is investigated through a hierarchy of GCM simulations using idealized and ''semirealistic'' boundary conditions in a high-resolution version of the Hadley Centre atmosphere model (HadAM3). This framework captures the large-scale essence of features such as the North and South American continents, Eurasia, and the Rocky Mountains, enabling the results to be applied more directly to realistic modeling situations than was possible with previous idealized studies. The physical processes by which the forcing mechanisms impact the large-scale flow and the midlatitude storm tracks are discussed. The characteristics of the North American continent are found to be very important in generating the structure of the North Atlantic storm track. In particular, the southwest–northeast tilt in the upper tropospheric jet produced by southward deflection of the westerly flow incident on the Rocky Mountains leads to enhanced storm development along an axis close to that of the continent's eastern coastline. The approximately triangular shape of North America also enables a cold pool of air to develop in the northeast, intensifying the surface temperature contrast across the eastern coastline, consistent with further enhancements of baroclinicity and storm growth along the same axis.

The Basic Ingredients of the North Atlantic Storm Track. Part I: Land–Sea Contrast and Orography

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First order: mountains and land/sea distribution determine storm track position

1 JULY 2009 JOURNAL OF CLIMATE

The Effect of Ocean Dynamics and Orography on Atmospheric Storm Tracks

CHRIS WILSON
Proudman Oceanographic Laboratory, and Department of Earth and Ocean Sciences, University of Liverpool, Liverpool, United Kingdom

BABLU SINHA
National Oceanography Centre, Southampton, United Kingdom

RICHARD G. WILLIAMS

Comparison of Simulated Storm Tracks for:

1. Coupled GCM (intermediate GCM).
   {FORTE Forster et al. 2000}
2. AGCM with no mountains, no horizontal ocean heat transport (OHT)

Run the models to steady state in annual mean, then study northern hemisphere winter (DJF).

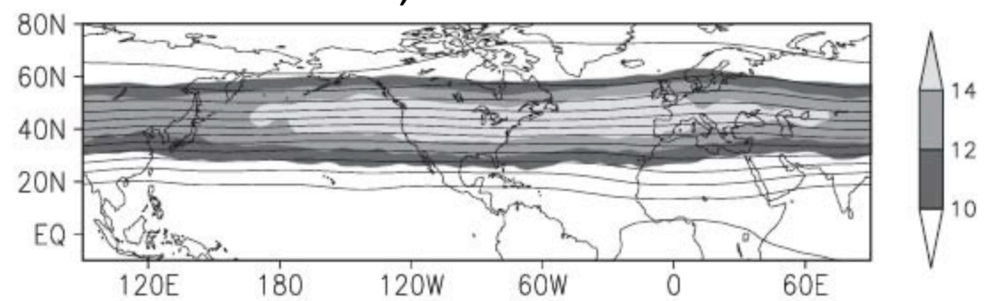
Results:

Without mountains or ocean circulation, there is still a storm track.

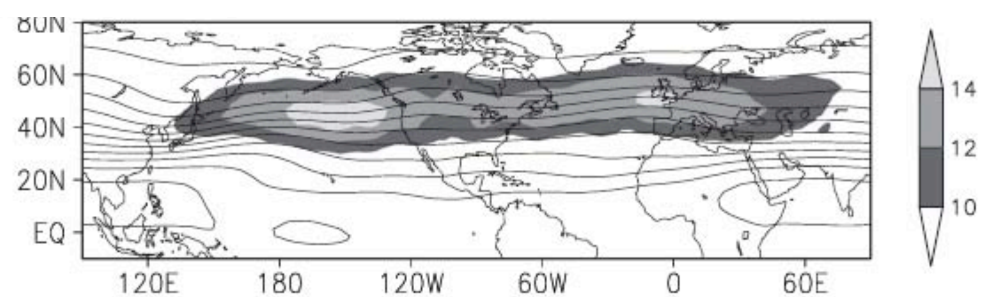
Storm Track is stronger, and zonal asymmetry is weak.

Bandpass Filtered Eddy Kinetic Energy (ms^{-1}) + Stream Function at 250 hPa

No mountains, no ocean circulation



Yes mountains, yes ocean circulation



Comparison of Simulated Storm Tracks when adding orography and ocean circulation separately.

Results:

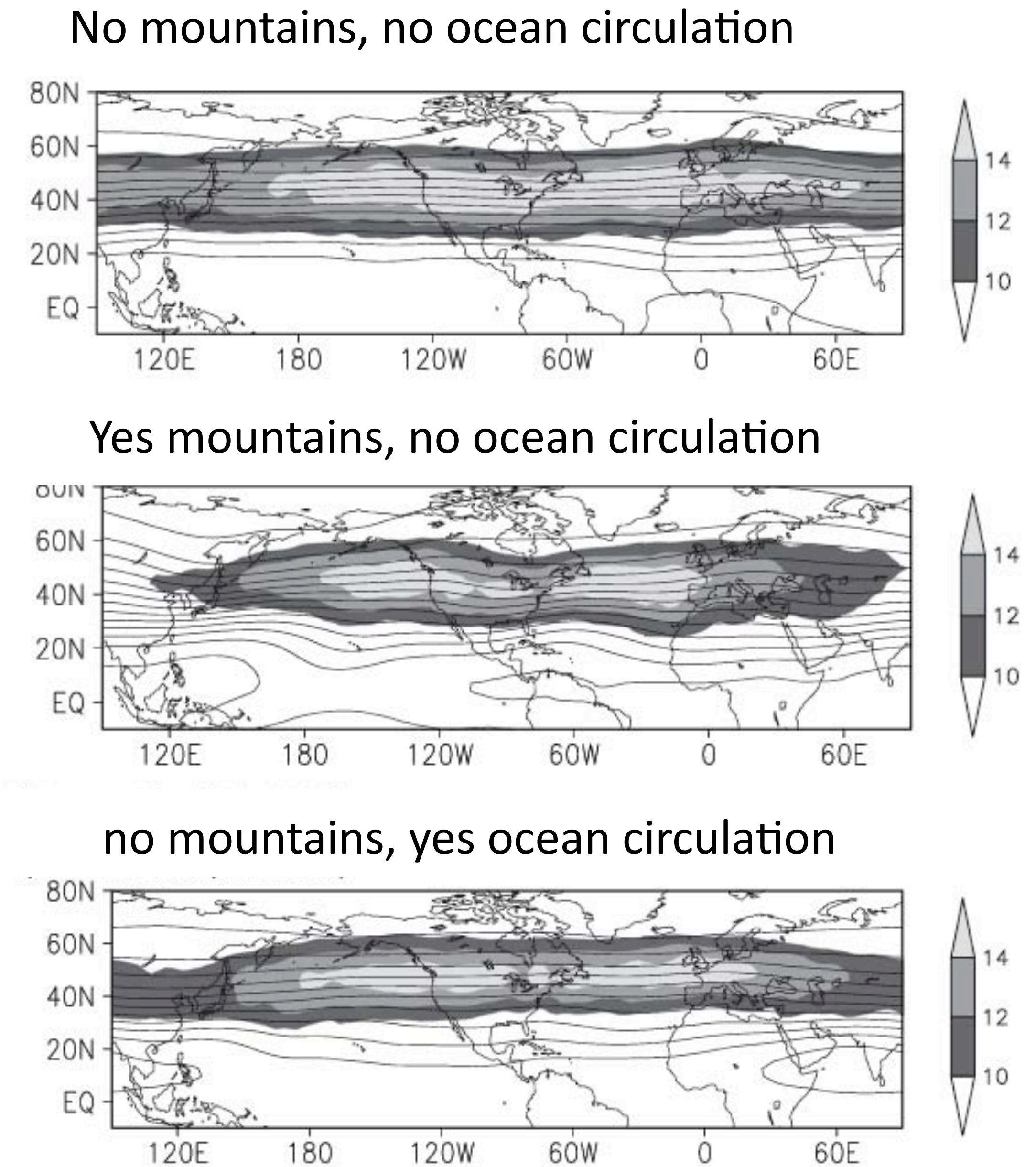
-Mountains create zonal asymmetry in the mean flow and storm tracks

(model stationary waves are weaker than observations)

-Ocean circulation causes the storm track to shift north

(model Gulf Stream is too strong)

Storm Track : Filtered EKE at 250hPa



Wilson et al. 2009

Combining the effects of Mountains and Ocean on storm forcing

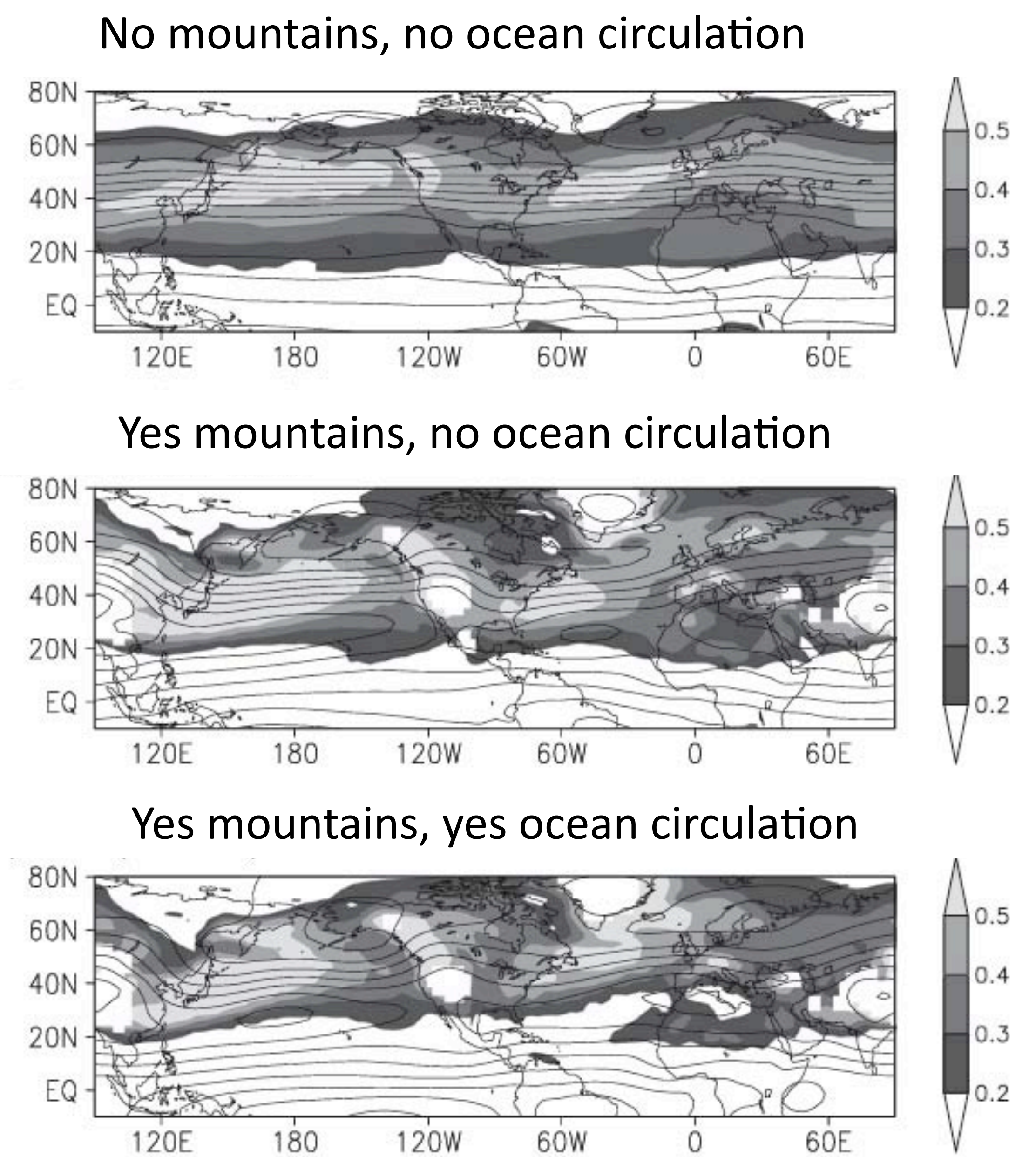
Mountains:

deflect the atmospheric jet, force more continental air southeastward over the ocean.

Ocean dynamics:

tighten SST gradients in western ocean basins →
changes overlying baroclinicity →
poleward shift in the mean winds.

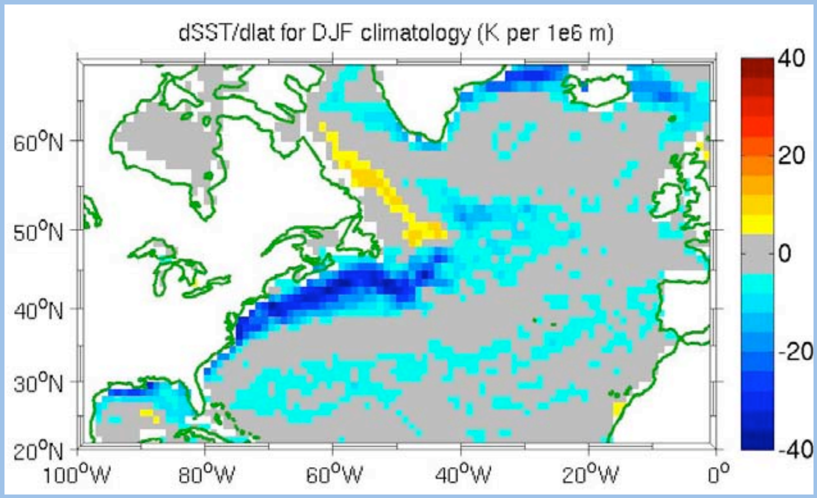
Baroclinicity (shading, day^{-1}) and Stream Function (contours) at 750-hPa



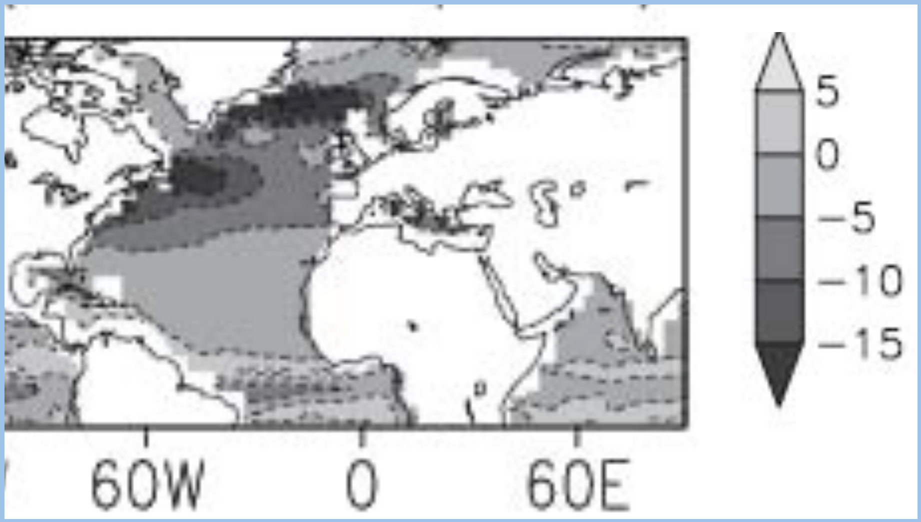
Wilson et al. 2009

Biases in storm track and Gulf Stream in Wilson et al. model are consistent

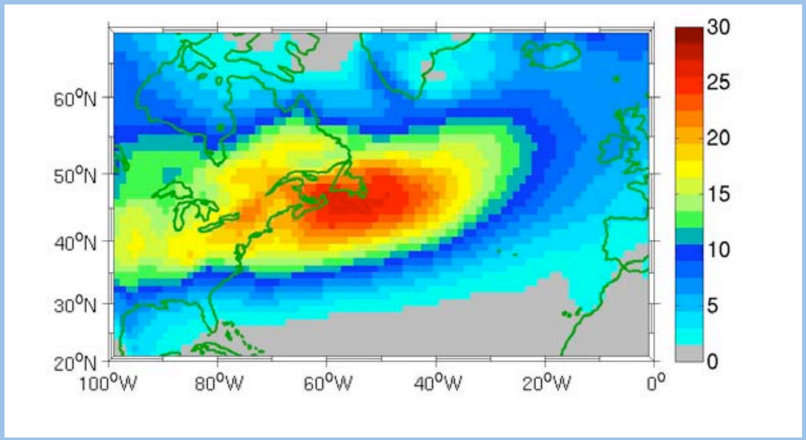
Meridional gradient in Sea Surface Temperature



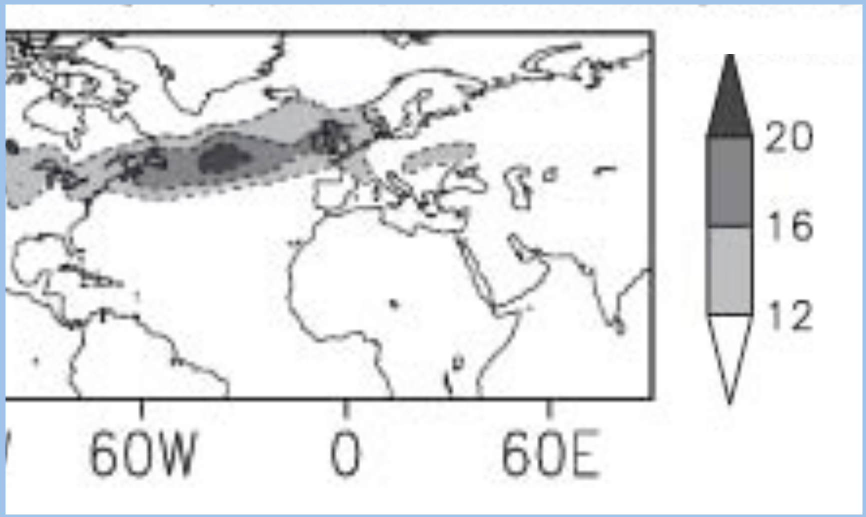
SST data source: NOAA OISST



Storm track (poleward eddy heat transport)



Atmosphere Data Source: ERA-40



Poleward Heat Transport vs. Boundary condition forcing of Dynamics

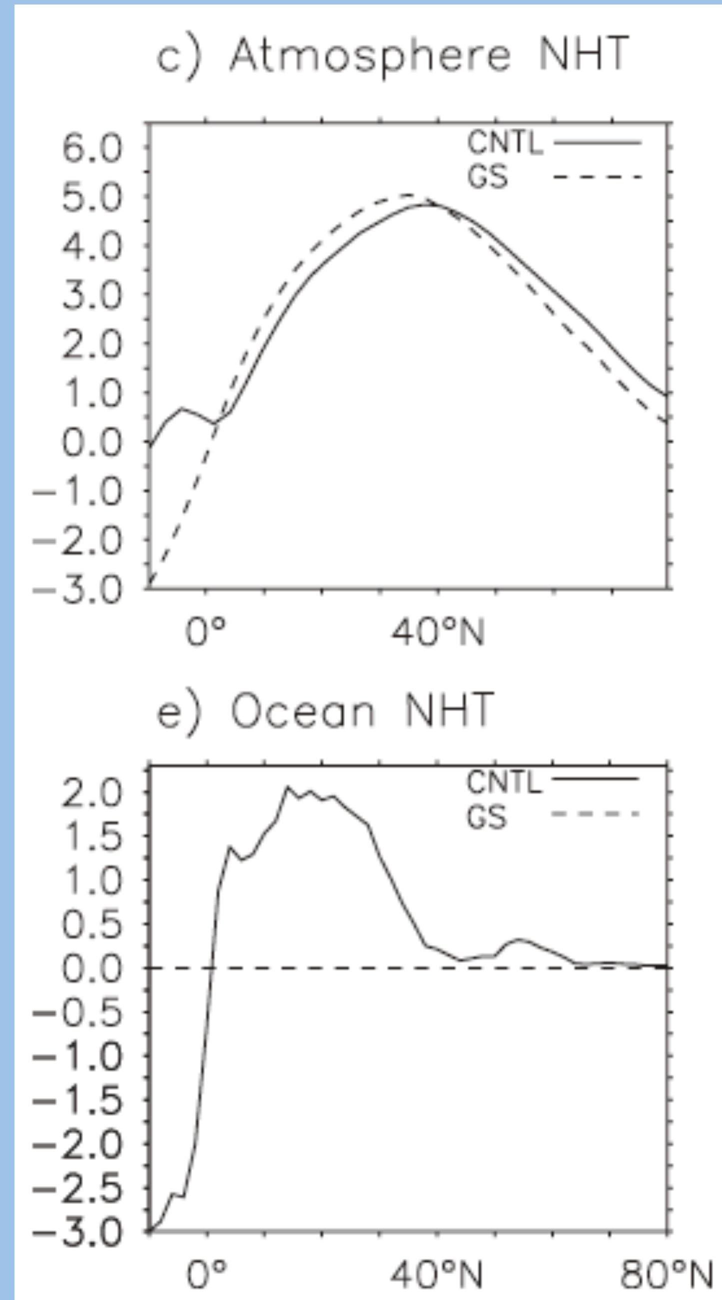
Wilson et al. theorize:

Ocean transport of heat in the tropics leads to a poleward shift in the maximum atmospheric northward heat transport: the atmospheric heat transport reduces in the tropics and increases in the mid and high latitudes. Accompanying this poleward shift in the maximum atmospheric heat transport is a concomitant shift in the midlatitude storm tracks, which is to be expected because the synoptic-scale eddies are the dominant process fluxing heat poleward at midlatitudes. The effect of the ocean dynamics on the storm track is most pronounced over the Atlantic basin where the ocean poleward heat transport is largest.

I contend:

It is not the heat transport itself that has an effect. The heat transport changes the surface forcing of midlatitude storms, which changes the atmospheric heat transport. (do we disagree, or is this just a technicality on semantics?)

Zonally integrated northward heat transport (PW).



Wilson et al. 2009

Key points of Brayshaw et al.

Storm track distribution of North Atlantic depends primarily on:

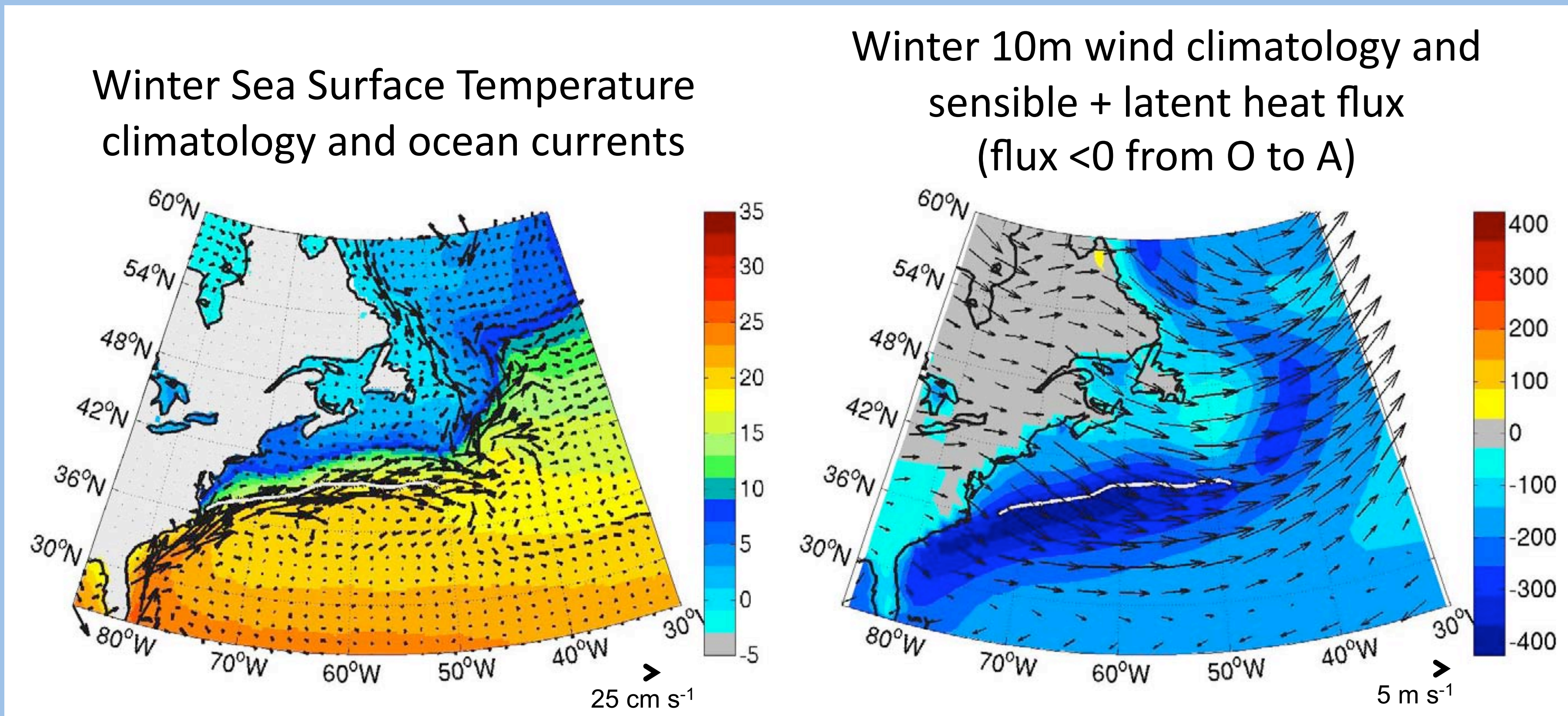
-Orographic deflection of the westerly jet

-Orientation of North American continent allows cold air to 'pool' in the northeast, intensifying the surface contrast.

Key points from Wilson et al.

Storm position can be shifted by the western boundary current influence on the low level baroclinic zone.

A simple theory on Gulf Steam Forcing of the mean storm track:
maintenance of the baroclinic zone throughout each winter



Wintertime Climatological SST (sea surface temperature) distribution:

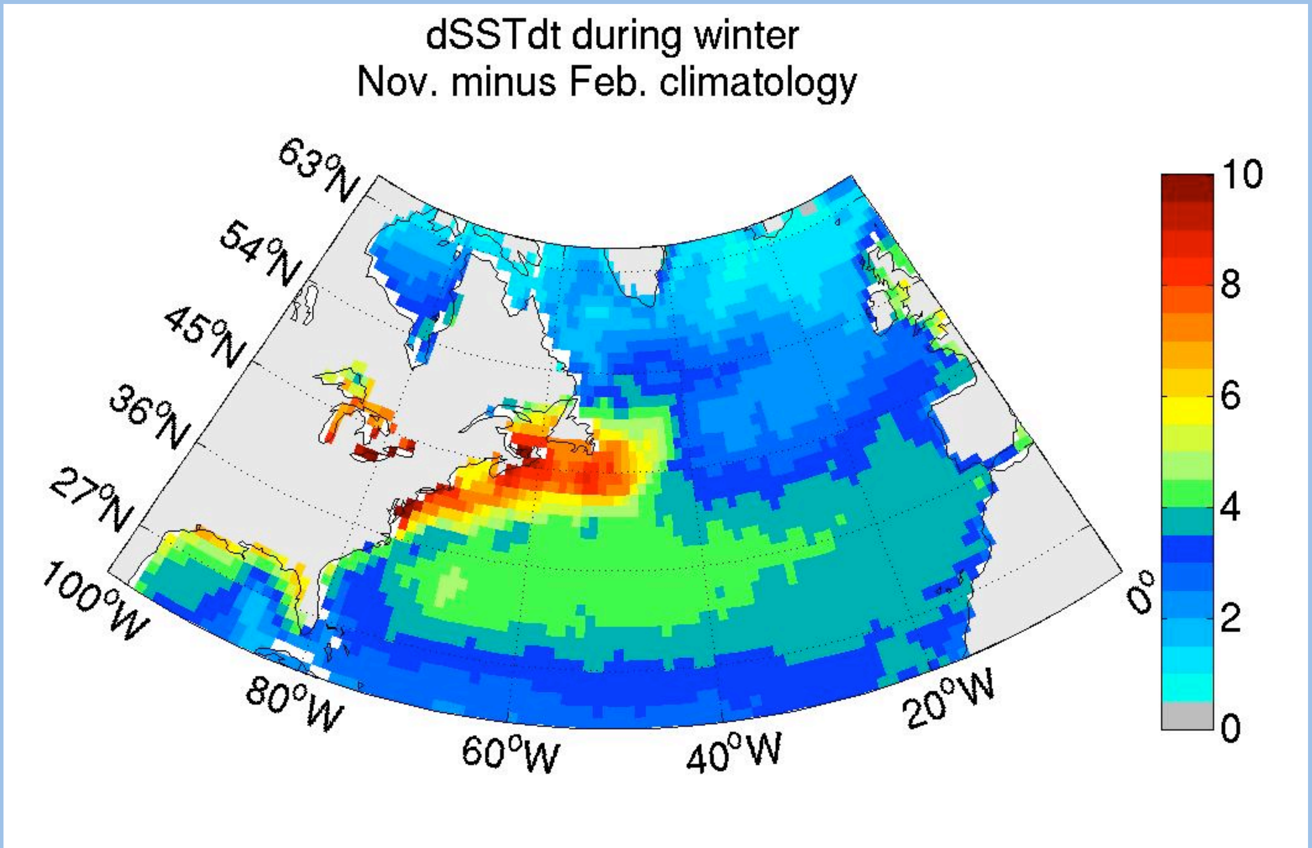
Strong meridional gradient that start at the north edge of the Gulf Stream.

Mean atmospheric conditions: continental air advected over the ocean (usually as a part of midlatitude storms systems) leading to strong surface heat fluxes

A simple theory on Gulf Steam Forcing of the mean storm track:
maintenance of the baroclinic zone throughout each winter

Atmospheric circulation causes cooling of the ocean surface during winter.

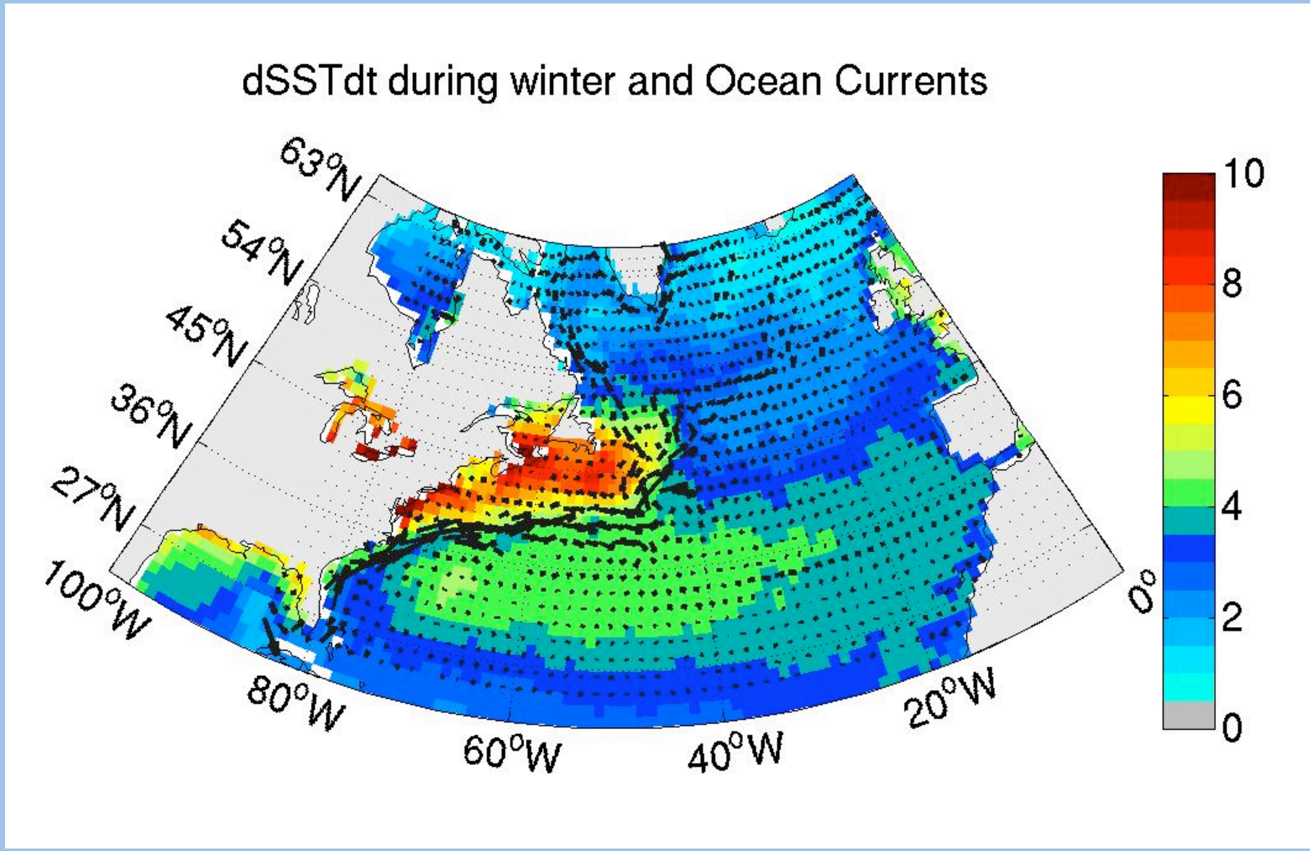
During summer this water is warmed by radiative and sensible heating, allowing the process to repeat itself each winter.



A simple theory on Gulf Steam Forcing of the mean storm track:
maintenance of the baroclinic zone throughout each winter

Atmospheric circulation causes cooling of the ocean surface during winter.

Maximum cooling occurs north of the Gulf Stream, with abrupt edge at ocean currents.

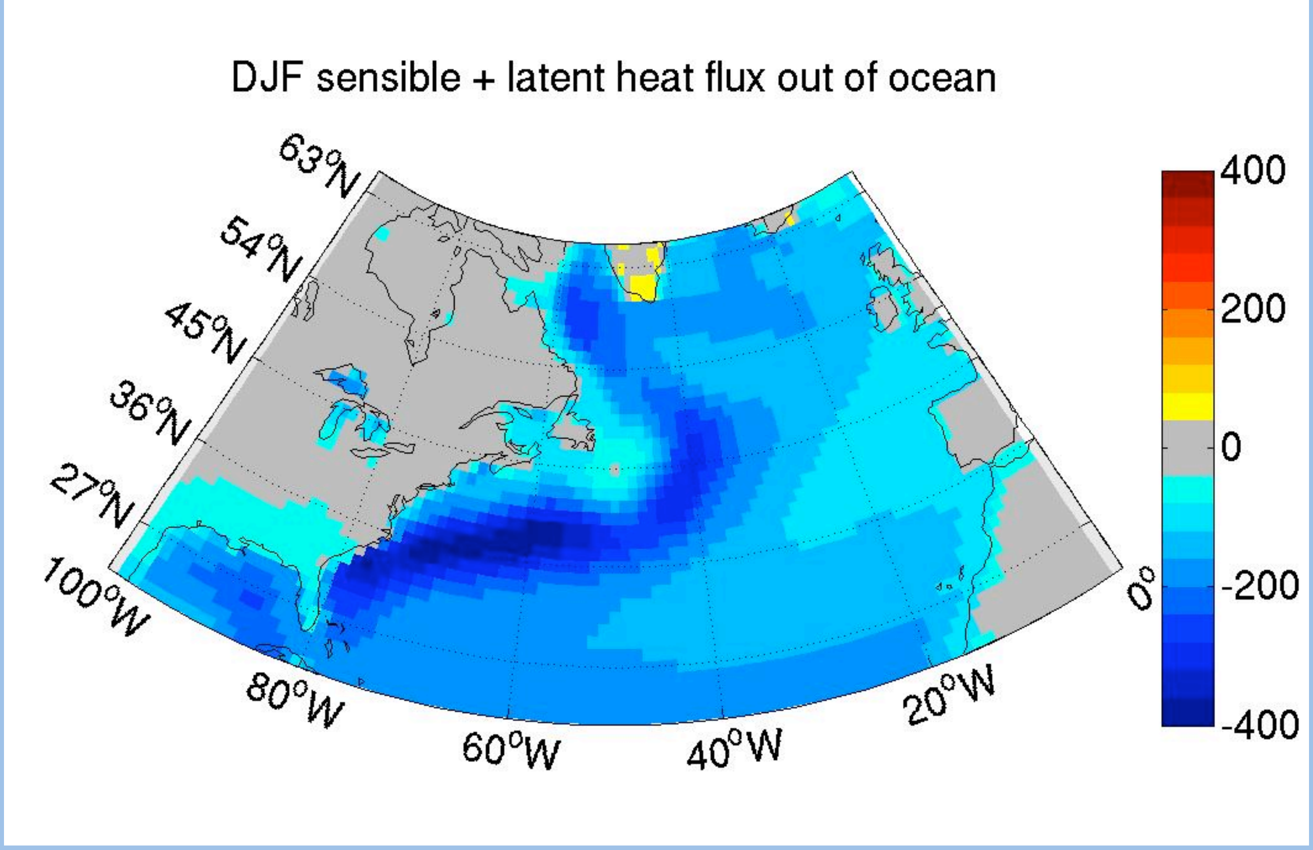


A simple theory on Gulf Steam Forcing of the mean storm track:
maintenance of the baroclinic zone throughout each winter

Key:
Maximum sensible and latent heat flux loss from ocean:

Coincides with region of warm Gulf Stream Current

Does not occur in the region of cooling SST.



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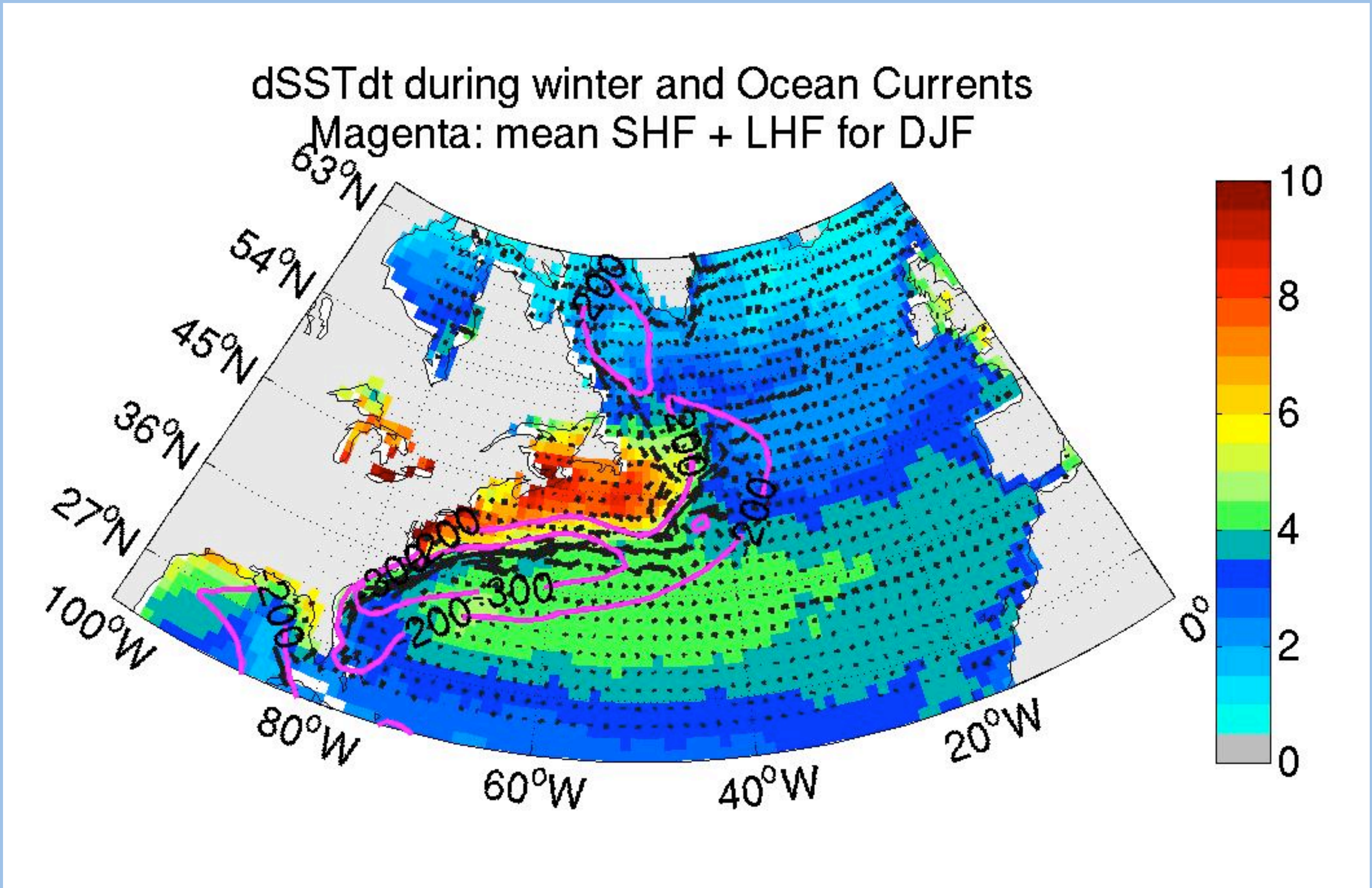


Offline Experiment Without Ocean Circulation

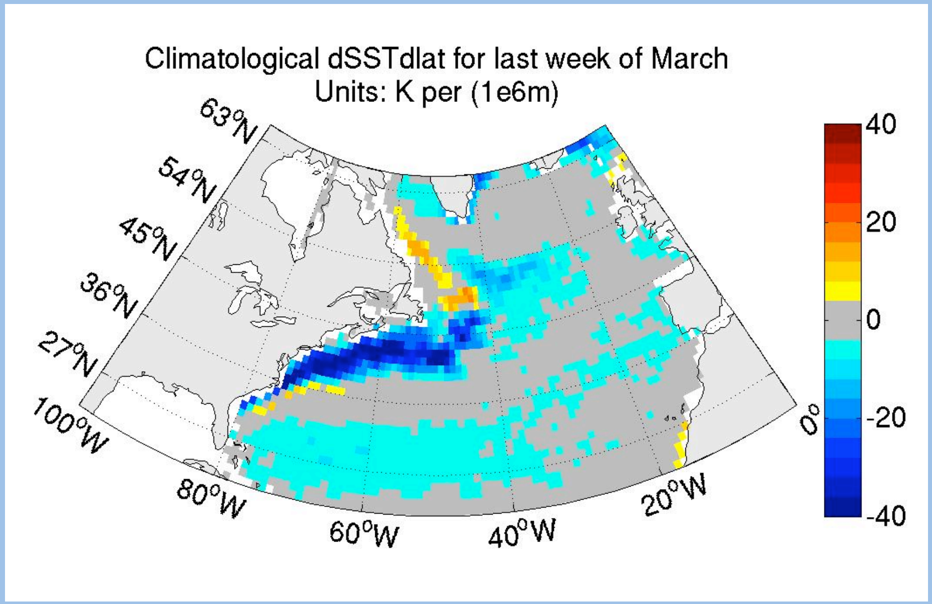
Courtesy of: Suzanne Dickinson

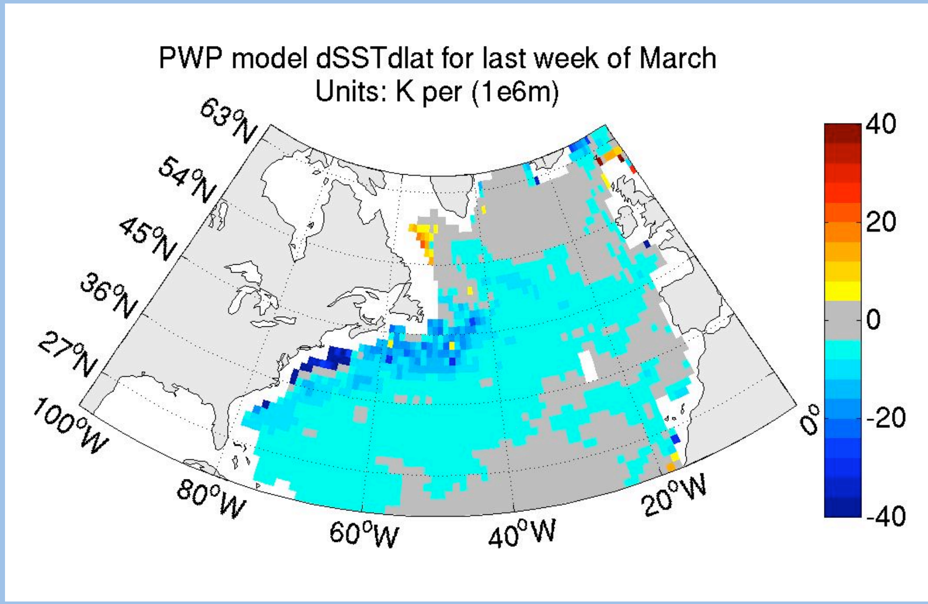
Price Weller Pinkel (PWP) Mixed Layer Model
[Price et al. 1986]

Run the model for one winter, turning off the ocean heat transport.

Result:

Strong meridional temperature gradient north of the Gulf Stream is largely wiped out by the end of winter.





Summary:

-over the course of winter, atmospheric circulation cools the ocean off the east coast of N. America

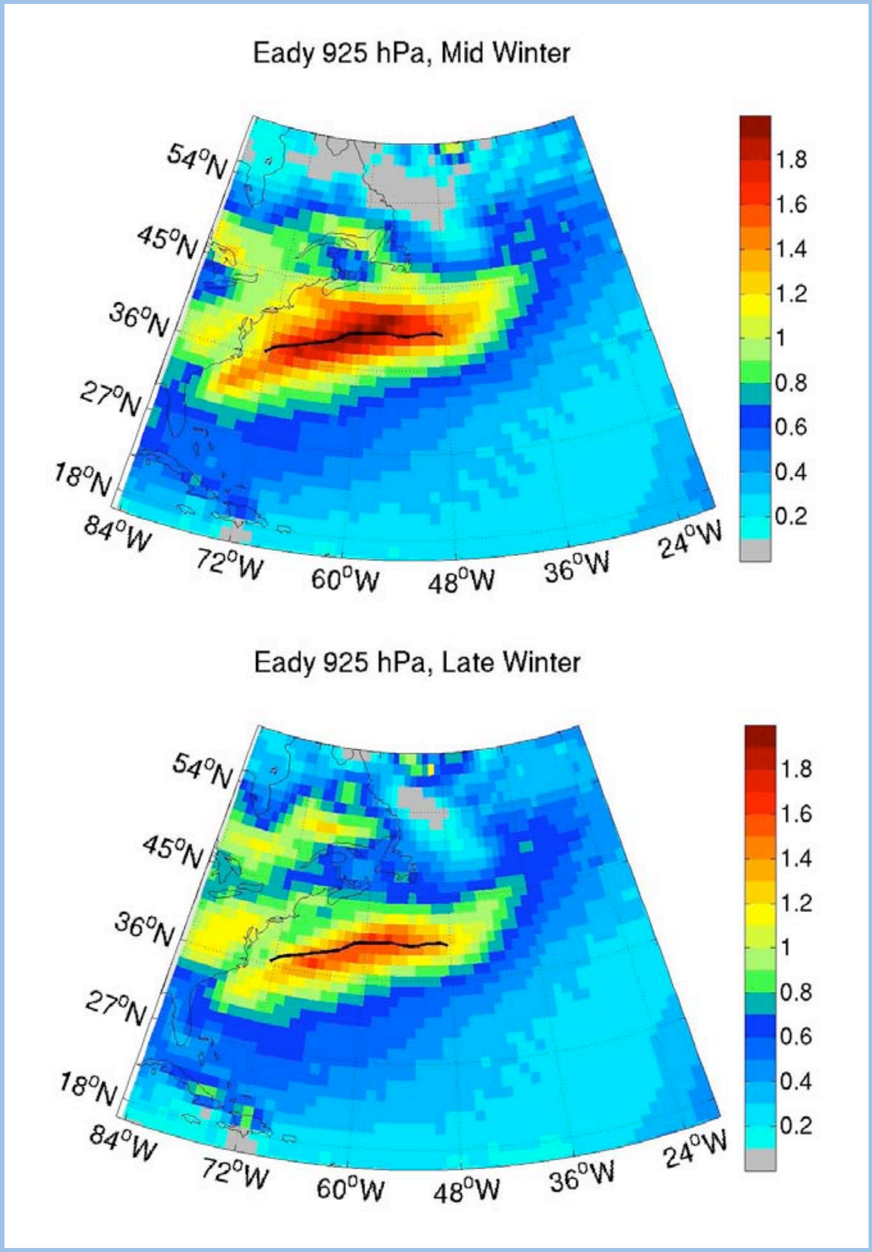
-ocean circulation replenishes the heat in the upper ocean along the Gulf Stream.

-this anchors the position of the storm track throughout winter.

In addition:

Woolings et al. (2009)

Regional modeling experiments show that increasing spatial and temporal resolution of SST boundary condition improves the mean position of the storm track.



Summary:

-over the course of winter, atmospheric circulation cools the ocean off the east coast of N. America

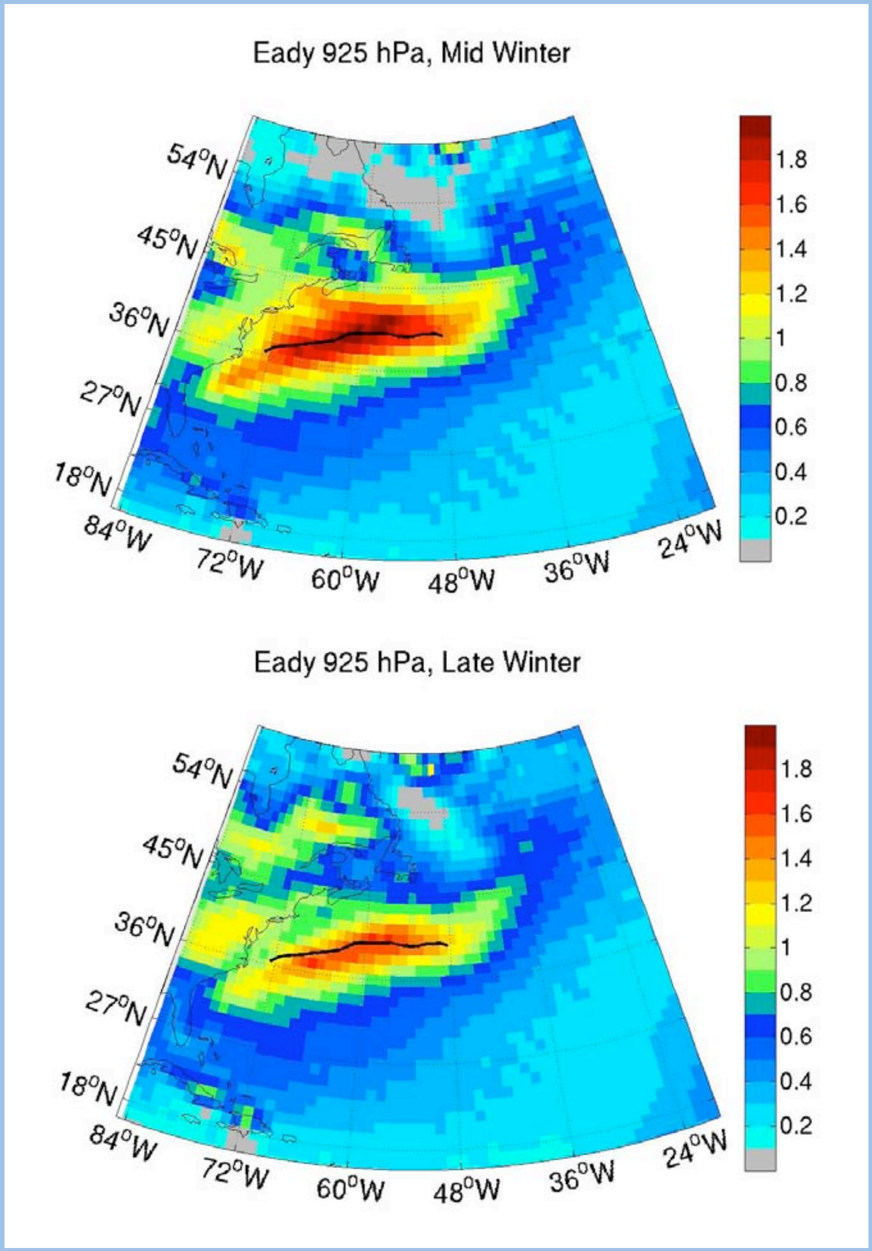
-ocean circulation replenishes the heat in the upper ocean along the Gulf Stream.

-this anchors the position of the storm track throughout winter.

In addition:

Woolings et al. (2009)

Regional modeling experiments show that increasing spatial and temporal resolution of SST boundary condition improves the mean position of the storm track.



Thankyou.